

## **DWR FAP GRANT PROPOSAL**

September 7, 2012

***Project Name:***

“Field test of a novel wetland treatment system to provide clean water for the Salton Sea Species Conservation Habitat”.

***Implementing Organization:***

University of California Berkeley Department of Plant & Microbial Biology

***Secondary Implementing Organization:***

***Proposed Start Date:***

January 1, 2013

***Proposed End Date:***

December 31, 2015

***Project Description:***

Our goal is to develop a novel constructed wetland water treatment system (CWTS) for the removal of Se, fertilizer nutrients and other contaminants from river water so as to provide a clean water supply for the SCH and other habitat related projects. This novel CWTS design has been successfully tested at UC Berkeley using mesocosms. The proposed research is to establish proof-of-concept under field conditions using a pilot CWTS located at a site adjacent to the Alamo River. The pilot CWTS will consist of a sedimentation basin, an algal treatment cell and a high density cattail treatment cell arranged sequentially. The function of the algal cell is to remove fertilizer nutrients and Se, a significant portion of which will be volatilized (volatilization leads to a net loss of Se from the local ecosystem, preventing its entry into the food chain). As the water containing Se-bearing algae flows into the cattail cell, more Se will be volatilized microbially by decomposition of algae and other organic matter; residual Se in the cattail cell will be immobilized in the sediments. With respect to the algal cell, its efficiency will be optimized by selecting the most suitable algal species and by manipulating growing conditions. The cattail treatment cell will be optimized by increasing the depth of the fallen litter layer to maximize an even flow of water through the Se-capturing sediment matrix, and by determining the residence time needed to reduce Se concentrations in the outflow to less than 1  $\mu\text{g Se/L}$ . The efficiency of Se and fertilizer nutrient removal will be determined by measuring the inlet and outlet Se, N, P and S concentrations for each treatment cell. In order to ensure a sustainable and ecologically safe ecosystem, the potential bioavailability and toxicity of any residual Se accumulating within the CWTS ecosystem will be monitored by x-ray absorption spectroscopy of the various Se species in sediments, plants and wildlife.

***Project Objective:***

The objective is to provide proof-of-concept for an innovative constructed wetland water treatment system (CWTS) developed at UC Berkeley for providing clean water to the SCH and other habitat related projects. This will be done by conducting field tests using a pilot CWTS constructed at a site adjacent to the Alamo River. In addition we propose to test different management strategies to enhance the removal of Se, especially through the environment-friendly Se volatilization pathway.

***Q1. Project Type:***

Research

***Q2. Project Description:***

The goal is to establish proof-of-concept for an innovative constructed wetland water treatment system (CWTS) to provide a supply of clean water to the SCH and other habitat related projects. A pilot CWTS (i.e., a sedimentation basin and 16 treatment cells) will be constructed by the Imperial Irrigation District next to the Alamo River. The objectives are to maximize the efficiency of Se and fertilizer nutrient removal by algal and cattail treatment cells arranged sequentially, to mitigate Se ecotoxic risk by enhancing the removal of Se to the atmosphere through Se volatilization, and to fully characterize (i.e., speciate) the chemical forms of any residual Se retained by the CWTS ecosystem. The research, which will take 3 years to complete, will provide a reliable, low-cost technology for generating a clean, low-salt water supply for species conservation habitats as well as an accurate assessment of the extent to which Se ecotoxicity has been mitigated by enhancing Se volatilization.

***Q3. Applicant Contact Information:***

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**General Project Information Questions**

***Q4. Project Team Qualifications:***

**1) University of California Berkeley research team**

Principal Investigator: Norman Terry

Professor Norman Terry will be the manager and the main person responsible for conducting the research project and coordinating research activities with Dr. Bruce Wilcox and his colleagues at the Imperial Irrigation District (IID). As the Principal Investigator for the research at UC Berkeley, he will lead a team of three postdoctoral scholars and several research assistants in carrying out the proposed experiments, analyzing the data and preparing reports for the funding agencies, IID and CADWR. Prof. Terry is a world leader in the environmental remediation of heavy metal and metalloid pollutants in water and soils. He has led four major constructed wetland projects for the cleanup of agricultural and industrial wastewaters: the Allegheny Power Service Constructed Wetland at Springdale, Pennsylvania, the Tennessee Valley Authority Constructed Wetland at Widows Creek, Alabama, the San Francisco Bay Constructed Wetland Treatment System at Richmond, California, and the Tulare Lake Drainage District Wetland at Corcoran, California. Prof. Terry pioneered the use of constructed wetland water treatment systems for the removal of Se from agricultural irrigation drainage water, research which continues to this day and has led to the current project. More details on his extensive scientific publications describing such projects are found in the attachments section together with his CV (*Attachment 3*).

Postdoctoral scholar 1: Dr. Jung-Chen Huang is a wetland engineer/ecologist. He obtained his Ph.D. from Ohio State University in Columbus in 2010. Since joining the Terry Lab, Dr. Huang carried out research on the project “*University of California Berkeley Salton Sea Research*” sponsored by the CADWR. During the past 2 1/2 years, Dr. Huang has carried out mesocosm studies, the purpose of which was to develop a “second generation” constructed wetland water treatment system with the ability to reduce Se to extremely low levels (*Huang et al., in press. Environmental science & Technology*) (see *Attachment 3* for his CV). Dr. Huang has the major responsibility for implementing the field research program to establish proof-of-concept of the proposed design of the constructed wetland treatment system (CWTS) to provide clean water to the Species Conservation Habitat.

Postdoctoral scholar 2: Dr. Soo In Yang is a microbiologist and expert in the field of synchrotron-based technologies (x-ray absorption spectroscopy). Dr. Yang obtained his Ph.D. from the University of Saskatchewan in Canada in 2011, where he conducted research in microbial Se transformation in biofilms. His research centered on the mechanisms by which biofilms detoxify bioavailable Se forms present in water (see *Attachment 3* for his CV and list of publications). Dr. Yang will contribute his synchrotron-based research expertise in the characterization of Se species contained in the different wetland ecosystem components in order to determine their potential bioavailability.

Research and management support: Dr. Maria C. Suarez is the laboratory manager under the supervision of Prof. Terry. Her function in this project will be to provide logistical support of the research activities. Dr. Suarez will also help in the preparation of reports for the funding agencies.

## 2) Research Partner - Imperial Irrigation District

Dr. Bruce Wilcox is the Environmental Program Manager for the Imperial Irrigation District (IID), Water Department, Agricultural Water Management Section, Environmental Mitigation Unit located at IID Operation Headquarters, J-15 in Imperial California. IID has generously agreed to fund the construction and participate in the operation and maintenance of the pilot CWTS described in this proposal. IID will provide the final design, logistics and support to build the CWTS in the Salton Sea (see Letter of Support in *Attachment 9*).

### *Q5. Related Experience:*

Prof. Terry has conducted four major studies involving the use of constructed wetlands for the cleanup of agricultural and industrial wastewaters. As principal investigator of each of these projects, he designed experimental research programs, secured the funds to support the research, hired the scientific personnel needed to conduct the projects, supervised the conduct of the research program and the analysis of the results obtained, prepared reports and published scientific papers associated with the work (*see Attachment #3, Norman Terry Selected Publications*). All this was done on budget and on time. Four field wetland studies done by the Terry Lab are described below.

1) The Chevron Wetland: In a joint project with the Chevron oil company, the Terry Lab conducted research on a 90-acre site at the Chevron oil refinery, Richmond, California. This study showed that constructed wetlands can remove a very high proportion of Se contaminants (mainly selenite-Se) from oil refinery wastewater. Inflow Se concentrations of 20 to 30 µg Se/L were reduced to less than 5 µg Se/L in the outflow. The wetland was able to process approximately 2 to 3 million gallons of refinery effluent per day. This study revealed that 20 to 30% of the toxic Se entering the wetland was released to the atmosphere in *non-toxic* volatile forms, a process known as “biological volatilization”. This is an extremely important pathway of Se removal since Se removed by volatilization cannot enter the local food chain.

2) The Tulare Lake drainage district wetland at Corcoran: The success of the research at the Chevron wetland led to our next wetland project at Corcoran, 60 miles north of Bakersfield. In this experiment, we built 10 quarter-acre wetland cells to test the idea that constructed wetlands can be used to solve one of the most serious problems confronting agriculture in California, i.e., the problem of what to do with Se-contaminated irrigation drainage water. Huge amounts of Se-contaminated water are being accumulated in thousands of evaporation ponds throughout California and other western states. Agricultural drainage water differs from industrial wastewater in that it is highly saline and contains several toxic metals in addition to Se. Each of the 10 wetland cells was planted with different plant species in mono- and mixed-cultures to determine the best plant species composition for maximum Se removal. The best of these wetland

cells removed 85% of the Se from the inflow as well as removing strontium and vanadium.

3 & 4) Tennessee Valley Authority and Allegheny Power Services wetlands: Electric utilities are mandated by the Clean Water Act to clean up their aqueous discharges. We carried out two separate studies, one at the Tennessee Valley Authority wetland in Alabama, and the other at the Allegheny Power Services wetland in Pennsylvania. The goal of this research was to develop optimal design criteria for building constructed wetlands. Both wetlands were shown to be capable of removing substantial amounts of toxic heavy metals including Mn and Fe, with the removal efficiency often exceeding 90%.

Our most recent research (April 1, 2010 - present day) was conducted in response to a request from, and funded by, the California Department of Water Resources. The purpose of the research was to develop a design for an innovative constructed wetland water treatment system to remove Se and fertilizer nutrients from river water in order to provide clean water for the Species Conservation Habitat at the Salton Sea. The first manuscript reporting on this research has now been accepted for publication in a peer-reviewed journal (*JC Huang, E Passeport and N Terry, 2012; Development of a Constructed Wetland Water Treatment System for Selenium Removal: Use of Mesocosms to Evaluate Design Parameters, Environmental Science & Technology, in press*).

## **Research Project specific questions**

### ***Q6. Project Type:***

This is a Research project

### ***Q7. Research Goals and Objectives:***

Our goal is to establish proof-of-concept for a novel constructed-wetland water treatment system (CWTS) for the removal of Se, fertilizer nutrients and other contaminants from river water so as to provide a clean water supply for the SCH and other habitat-related projects. The design of the CWTS was developed after a 2.5-year study at UC Berkeley. After successfully testing this design using mesocosms and pilot treatment systems under greenhouse conditions, we now wish to proceed to the next step, which is to test and improve the efficacy of the design under field conditions at the Salton Sea. The specific objectives are:

1) To construct a pilot CWTS consisting of a sedimentation basin and 16 treatment cells at a site adjacent to the Alamo River. The pilot system design and location are described in *Attachment 7* and will be built and maintained by the Imperial Irrigation District (IID).

- 2) To establish proof-of-concept of the proposed CWTS design by determining its efficiency for removing Se, fertilizer nutrients and other pollutants from river water to be obtained from the Alamo River.
- 3) To maximize the efficiency of the CWTS design in terms of its ability to remove pollutants by determining the minimum wetland residence time for maximum pollutant removal.
- 4) To determine the most appropriate algal species and algal population density for maximizing the removal of Se from river water through Se volatilization.
- 5) To determine the changes in pollutant removal efficiencies (i.e., for Se, N, P and S) as the wetland matures over the 3-year experimental period.
- 6) To determine the extent to which Se ecotoxicity within the CWTS ecosystem can be mitigated by the inclusion of an algal treatment cell. This will be tested by determining the amounts and chemical forms of residual Se that accumulates in the algal-cattail treatment systems with four different algal population densities. The bioavailability (and therefore potential Se ecotoxicity) of the residual Se forms in each case will be determined by speciating the chemical forms of Se in plants, sediments and wildlife using x-ray absorption spectroscopy.

***Q8. Proposed Research:***

The research proposed is to test the concept that a constructed wetland water treatment system (CWTS) can be constructed to provide a low-cost, low-maintenance water treatment system for the cleanup of river water contaminated with Se, fertilizer nutrient and other pollutants. This low-salt clean water supply can then be used to support the proposed species conservation habitat at the Salton Sea.

The scientific basis for this approach is as follows. Constructed wetland studies have shown that substantial quantities of Se may be removed from oil refinery wastewater (Hansen et al., 1998) and agricultural drainage water (Gao et al., 2003; Lin and Terry, 2003). Although these early studies show that substantial quantities of Se could be removed from Se contaminated water, their rather primitive design did not permit Se concentrations in the outflow to be less than 5 µg Se/L. In April 2010, we began a series of studies at UC Berkeley to improve the design of the water treatment system. This was achieved using a series of experiments with wetland mesocosms in a greenhouse. By testing a number of treatment options we developed an innovative design using a cattail-planted wetland mesocosm that was able to reduce Se concentrations in the water column from 15 µg Se/L to 0.1 µg Se/L within 72 hours.

A second concern with using constructed wetland water treatment systems for Se removal is that, over a number of years, potentially ecotoxic chemical forms of Se may be accumulated within the water treatment ecosystem. In order to mitigate this problem we

explored the idea of incorporating an algal treatment cell ahead of the cattail-planted cell to enhance removal of the Se from the ecosystem by volatilization. Algae have a considerable propensity to take up and volatilize Se directly; our research has shown that as much as 50% of the Se may be removed in this way. In addition, as the Se-containing algae flow into the cattail cell, they die and decay yielding still more volatile Se through microbial activity. Although we have obtained evidence in support of these conclusions under laboratory conditions, it is essential that these results are confirmed under field conditions in a pilot wetland at the Salton Sea.

Our research proposes to answer the following questions:

1. How efficiently can the pilot CWTS remove Se, fertilizer nutrients and other contaminants from river water obtained from the Alamo River?
2. What is the minimum residence time needed to achieve a given level of efficiency of contaminant removal?
3. What proportion of the water flow entering the CWTS reaches the outflow, i.e., how large are the losses due to evaporation and seepage? A related question is, how large should the treatment facility be in order to generate sufficient clean water to support the species conservation habitat?
4. Which management practices should be applied to enhance contaminant removal efficiency, especially with respect to Se?
5. To what extent can Se accumulation within the wetland ecosystem be mitigated by practices that enhance Se volatilization? A related question is, how much Se, and in what chemical forms, is Se accumulated in various components of the wetland ecosystem, including plants, sediments and wildlife, over time?

***Q9. Relevance to Program Goals:***

The primary goal of the Salton Sea Financial Assistance Program is to maintain and enhance habitat values for fish, birds and other wildlife, which are threatened by rising salinity levels. The salinity problem will be further aggravated as waters flowing to the Salton Sea are discontinued in accordance with the Quantification Settlement Agreement of 2003. In order to provide usable habitat for fish and wildlife, alternative *low-salt* clean water supplies are desperately needed, and as soon as possible. The only alternative water supplies available to the Salton Sea come from agricultural irrigation drainage water and local rivers such as the Alamo River and the New River (the Alamo and New Rivers have average salinity concentrations of 2.0 and 2.6 ppt, respectively, C. Holdren, Reclamation, unpublished data). All of these water sources are contaminated with fertilizer nutrients, particularly nitrogen and phosphorus, as well as Se. Fertilizer nutrient entering the species conservation habitat presents particularly serious problems because it leads to eutrophication and fish death. Piscivorous birds are therefore cutoff from a major food source.

The proposed research is designed to produce substantial quantities of clean water using water from local rivers which has been treated to remove Se and fertilizer nutrients. Because the treated effluent water coming from the CWTS is essentially low-saline fresh water, it can be readily mixed with Salton Sea water to help maintain salinity at levels low enough to support a functioning and usable habitat for fish and wildlife. Based on the EIS/EIR draft report (*DWR, 2011. Project Operations. Environmental Impact Report for the Salton Sea SCH Project*), the SCH ponds would most likely be operated in the range of 20 to 40 parts per thousand (ppt) salinity. Water from the Alamo River (or New River) with salinities of ~2-3 ppt could be blended with water from the Salton Sea with a current salinity of ~53 ppt to produce the desired pond salinity. Blending the river water and seawater in different amounts would allow for a range of salinities to be used in the SCH ponds.

**Q10. Research Methods:**

*Hypotheses.* The main hypothesis to be tested is that using a combination of algal- and cattail-planted treatment cells it will be possible to create a highly efficient water treatment system that: 1) removes Se (and fertilizer nutrient, e.g., N, P and S) from the river water to extremely low levels, and 2) substantially reduces the accumulation of Se in the CWTS ecosystem due to the fact that Se will be volatilized to the atmosphere by algae, microbes and plants. The *central and key part of the pilot wetland* will consist of 4 separate 2-cell treatment components, each of which will be arranged as shown:

| 2-cell treatment component |  
River water  $\Rightarrow$  sedimentation pond  $\Rightarrow$  | **algal cell**  $\Rightarrow$  **cattail cell** |  $\Rightarrow$  outflow to playa

The main purpose of the algal treatment cell is to achieve a substantial removal of Se from river water by volatilization to the atmosphere. By this means we will greatly diminish the accumulation of Se (especially potentially ecotoxic forms of Se) within the CWTS ecosystem. Selenium volatilized to the atmosphere results in a net loss of Se from water, sediments, plants and other wildlife within the local ecosystem. Selenium will be volatilized through direct algal metabolism of absorbed selenate (Terry, et al., 2000). As the Se-bearing algae flow from the algal treatment cell to the cattail treatment cell, more Se will be volatilized through the action of microbes as they metabolize (decompose) the algae at the surface of the cattail sediments.

*Research overview.* The narrative describing the field research plan (including the construction and design, monitoring, location, site characteristics, setup, list of experiments, field sampling methods, water budget calculation, analytical methods, and statistical analyses) are presented in *Attachment 7*. The map of the location, figures illustrating the CWTS design and other figures illustrating the research plan are presented in *Attachment 8*.

The first step in the field test of the CWTS design is to determine the minimum residence time needed to achieve maximum removal of Se and fertilizer nutrients (e.g., N, P and S)

by the cattail-planted wetland: residence times of 3, 6, 9 and 12 days will be tested (Experiment 1). In Experiment 2 the algal treatment cells will be set up with varying algal population densities in order to answer two specific questions: 1) Does the inclusion of an algal treatment cell significantly reduce the amount of Se (especially ecotoxic forms of Se) accumulated in the cattail-treatment cell, and 2) if such a reduction is obtained, what is the quantitative effect of varying algal population density on achieving this Se reduction? In Experiment 3, we will test 4 different algal species with respect to their efficiency of pollutant removal (especially by volatilization).

Experiment 4 is concerned with the changes that take place as the cattail treatment cell matures. Previous research has shown that constructed wetlands may become more efficient in removing pollutants as they mature (Zhang et al., 2003). By following the efficiency of Se, N, P and S removal over the three year period we will determine the extent to which wetland maturity affects pollutant removal efficiency. The hypothesis that Se ecotoxicity within the CWTS ecosystem can be mitigated by the inclusion of an algal treatment cell to remove Se through volatilization will be tested by determining the amounts of residual Se that accumulates in the CWTS ecosystem over time in each of the four algal-cattail treatment components. The bioavailability of the residual Se forms will be determined by speciating the chemical forms of Se in plants, sediments and wildlife using x-ray absorption spectroscopy.

***Q11. Timeframe:***

Year 1: The proposed CWTS will be built in January 2013 by the Imperial Irrigation District collaborator agency (IID) at a 10-acre site near the Alamo River, based on the design provided by UC Berkeley. During the same month, planting will be conducted and the long term monitoring will be initiated for the wetland maturity experiment. Once the cattail and algal population are established during the next four months, we will start the residence time and algal experiments (May 2013). All the experiments and monitoring will continue for the duration of the CWTS research program.

Years 2 and 3: The work will be continued in the field and in the laboratory to assess the progress and long-term performance of the CWTS. Adjustments in the design and operation of the CWTS will be made based on the results from the previous year as required.

For the duration of the experimental work, we will gather samples periodically for laboratory analysis at UC Berkeley and XAS analysis at Stanford University. Quarterly, annual and final reports on the research will be provided as required by the funding agencies (see *Attachment 5 Schedule*).

***Q12. Phasing:***

In order to provide proof-of-concept for this water treatment system, we believe that it will take a full 3-year research program. The first year will be taken in constructing, planting and establishing the CWTS, and in carrying out the first set of monitoring experiments. The second and third years will be needed to properly assess the changes occurring in response to wetland maturity, i.e., changes in pollutant removal efficiency, and in the buildup and speciation of residual Se in the CWTS ecosystem. However, if the project is shortened to 2 years, this would provide useful information as to removal efficiency and Se buildup but would not be sufficient to determine the sustainability of the CWTS over time.

***Q13. Benefits of the Research:***

The Salton Sea ecosystem is currently facing two major problems, diminishing water supplies and increasing salinity, both of which will result in loss of habitat for fish and wildlife. To compensate for this loss of habitat along the shores of the Salton Sea, it has been proposed to construct a Species Conservation Habitat (SCH), as mandated by the Salton Sea Restoration Fund (DWR, 2010). If untreated water (e.g., from the Alamo River or New River) is used to supply the SCH, there may well be additional problems of eutrophication and Se ecotoxicity. Both rivers contain fertilizer nutrients and Se, as well as total suspended solids, all of which can damage the delicate Salton Sea ecosystem. The major benefit of this research therefore is that it will facilitate the development of a cost-effective water treatment system for treating river water, thereby providing a low-salt clean water supply to support the SCH.

Selenium, a teratogen, is especially problematic to fish and birds because of its biomagnification within the food web. Our research will further the goals of the Program by developing and evaluating a combined algal-cattail treatment system to minimize Se buildup by enhancing Se volatilization to the atmosphere. The effectiveness of this approach will be validated, first, by monitoring the buildup of Se in the CWTS ecosystem over time, and second, by determining the bioavailability and therefore potential Se ecotoxicity using high energy x-ray absorption spectroscopy to speciate Se in sediments, plant and animal tissues. Thus, this research will provide a thorough assessment of the effectiveness of the proposed design in mitigating Se eco-toxicity within the CWTS ecosystem. The main species to be protected by this clean water treatment system include regional endangered species and other species of special concern such as desert pupfish (*Cyprinodon macularius*), and California brown pelican (*Pelecanus occidentalis californicus*), migratory birds (*Podiceps nigricollis*, *Calidris mauri*), colonial breeding water birds (*Gelochelidon nilotica*, *Rynchops niger*), breeding shore birds (*Recurvirostra americana*, *Himantopus mexicanus*), and other piscivorous birds that rely on the current fish resources at the Salton Sea (*Pelecanus erythrorhynchos*, *Phalacrocorax auritus*).

**Attachments index:**

*Attachment 1-* Letter of authorization to apply for the CADWR grant

*Attachment 2-* Applicant team

*Attachment 3-* CVs Applicant team

*Attachment 4-* Work plan

*Attachment 5-* Schedule

*Attachment 6-* Budget

*Attachment 7-* Field research plan

*Attachment 8-* Site map, design figures and tables

*Attachment 9-* Letters of recommendation:

- Imperial Irrigation District - IID
- Professor Gary Sposito
- Dean of the College of Natural Resources

*Attachment 10-* Operation and maintenance plan

*Attachment 11-* References

## Attachment 1. Letter of authorization to apply for the CADWR grant

UNIVERSITY OF CALIFORNIA, BERKELEY

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August 27, 2012

**Vivien L. Maisonneuve**  
*Staff Environmental Scientist*  
**Department of Water Resources**  
*FloodSAFE Environmental Stewardship and Statewide Resources Office*  
*Salton Sea Program*  
*901 P Street, Room 411-A*  
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Dear Vivien,

By this letter I am confirming that I am the designated project manager (Principal Investigator) for the project proposal entitled, "*Field test of a novel wetland treatment system to provide clean water for the Salton Sea Species Conservation Habitat*".

The Chair of my department (Plant & Microbial Biology), Prof. Robert Fischer, confirms below that I am authorized to apply for this grant on behalf of the University of California Berkeley Department of Plant & Microbial Biology.

Sincerely,

A handwritten signature in black ink that reads "Norman Terry".

Norman Terry  
Professor of Plant Biology.

A handwritten signature in black ink that reads "Robert Fischer".

Cosigned by Prof. Robert Fischer, Chair:



## Sponsored Projects Office

University of California, Berkeley  
2150 Shattuck Avenue, Suite 313  
Berkeley, CA 94704-5940



**Principal Investigator: Norman Terry**

**Fellow:**

**Project Title: Field Test of a novel wetland treatment system to provide clean water for the Salton Sea Species Conservation Habitat**

**Proposal to the CA Department of Water Resources (DWR)-FloodSAFE  
Environmental Stewardship and Statewide Resources Office (FESSRO)**

Please accept the enclosed proposal submitted on behalf of The Regents of the University of California Berkeley campus. Should this proposal be selected for funding, award documents should be issued using the information provided below.

Endorsed for the Regents by:

Christine Luppino  
Research Administrator

If you have any questions or need additional information regarding this proposal, please contact:

Christine Luppino  
Phone: (510) 643-6113  
Fax: (510) 642-8236  
Email: [cluppino@berkeley.edu](mailto:cluppino@berkeley.edu)

<b>AWARDS SHOULD BE MADE TO:</b>	<b>CHECKS SHOULD BE MADE PAYABLE TO:</b>
<b>The Regents of the University of California</b>	<b>The Regents of the University of California</b>
c/o Sponsored Projects Office University of California, Berkeley 2150 Shattuck Avenue, Suite 313 Berkeley, CA 94704-5940	<b>CHECKS SHOULD BE SENT TO:</b>
email address for electronics awards: <a href="mailto:spoawards@berkeley.edu">spoawards@berkeley.edu</a>	Extramural Funds Accounting attn: Todd Vizenor University of California, Berkeley 2195 Hearst Avenue, Room 130 Berkeley, CA 94720-1103 Telephone: 510-643-6277 Fax: 510-666-2559
Main Office: 510-642-0120 Fax: 510-642-8236 Website: <a href="http://spo.berkeley.edu">http://spo.berkeley.edu</a>	

## ***Attachment 2. Applicant team***

### **Principal Investigator:**

Professor Norman Terry

### **Project Team:**

- Dr. Jung-Chen Huang, postdoctoral scholar, wetland engineer/ecologist
- Dr. Soo In Yang, postdoctoral scholar, microbiologist and expert in x-ray absorption spectroscopy
- Dr. Maria Suarez, research and management support, plant biochemist and molecular biologist.

### Attachment 3. CVs of Applicants team

## Norman Terry *Curriculum vitae*

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### EDUCATION

**Ph.D. Plant Physiology 1966**

*University of Nottingham, Nottingham, UK*

**M.Sc. Plant Physiology 1963**

*University of Nottingham, Nottingham, UK*

**B.Sc. Botany (Special Honors) 1961**

*University of Southampton, Southampton, UK*

### APPOINTMENTS

**1989-present Professor\***

*Department of Plant and Microbial Biology, University of California at Berkeley*

**1984-1989 Professor\***

*Department of Plant and Soil Biology, University of California at Berkeley*

**1978-1984 Associate Professor\***

*Department of Plant and Soil Biology, University of California at Berkeley*

**1972-1978 Assistant Professor\***

*Department of Soils and Plant Nutrition, University of California at Berkeley*

### TEACHING

I currently teach two upper division courses. In the Fall Semester of each year, I teach *Plant Biology 135 (Physiological and Biochemical Plant Biology, 3 units)*. This course is designed for students majoring in plant biology and other students seriously interested in plant physiology and biochemistry. In the Spring Semester of each year I teach *Plant Biology 180 (Environmental Plant Biology, 2 units)*. This course provides a multidisciplinary approach to the interactions of plants with their environment.

### RESEARCH ACTIVITIES

The first part of my research career centered on the study of the physiology and biochemistry of environmental stresses associated with water, mineral nutrients, salt (salinity), and toxic heavy metals. Since 1989 my research has focused on phytoremediation, the use of plants to clean up contaminated soil and water. My research approach is multidisciplinary in that my laboratory conducts research in ecology, plant physiology and biochemistry, microbiology, and molecular biology (including the genetic engineering of plants for enhanced phytoremediation). My major accomplishments include the development of the use of constructed wetlands to remove selenium and toxic heavy metals from agricultural and industrial wastewater, as well as the development of genetically engineered plants for the phytoremediation of selenium-contaminated soils. I have authored over 250 research publications, obtained 3 patents, and co-edited the book *Phytoremediation of Contaminated Soil and Water*, published by Lewis publishers, New York.

## PATENTS

- Terry, N., Pilon-Smits, E.A.H., Zhu, Y.L. "Heavy metal phytoremediation" US Patent 6576816. 10 June 2003.
- Terry, N., Pilon-Smits, E.A.H., de Souza, M. "Trace element phytoremediation" US Patent 6974896. 13 Dec. 2005.
- Terry, N., Pilon-Smits, E.A.H., Zhu, Y.L. "Heavy metal phytoremediation" US Patent 7034202. 25 Apr. 2006.

## RECENT PUBLICATIONS (2000 to present)

- Rao, I.M. and Terry, N. 2000. Photosynthetic adaptation to nutrient stress. *Chapter in: Probing Photosynthesis: Mechanism, Regulation and Adaptation*. M. Yunus, U. Pathre and P. Mohanty, eds. Taylor & Francis, London. Pp. 379-397.
- Zayed, A., Pilon-Smits, E.A.H., de Souza, M., Lin, Z. Q. and Terry, N. 2000. Remediation of Selenium-Polluted Soils and Waters by Phytovolatilization. *In: Phytoremediation of Trace Elements*. N. Terry and G. S. Bañuelos, eds. Ann Arbor Press, Michigan, pp. 61-84.
- Terry, N. and G. S. Bañuelos (eds.). 2000. *Phytoremediation of Trace Elements*. Lewis Publishers, Boca Raton. 389 pages.
- Terry, N., A.M. Zayed, M.P. de Souza and A.S. Tarun. 2000. Selenium in higher plants, *Ann. Rev. Plant Physiol. Plant Mol. Biol.*, 51:401-32.
- Lin, Z-Q., R.S. Schemenauer, V. Cervinka, A. Zayed, A. Lee and N. Terry. 2000. Selenium volatilization from the soil-*Salicornia bigelovii* Torr. treatment system for the remediation of contaminated water and soil in the San Joaquin Valley, *J. Environ. Quality*, 29:1048-1056.
- de Souza, M.P., C.M. Lytle, M. Mulholland, M.L. Otte and N. Terry. 2000. Selenium assimilation and volatilization from dimethylselenoniopropionate (DMSeP) by Indian mustard, *Plant Physiol.*, 122:1281-1288.
- Pilon-Smits, E.A.H., Y.L. Zhu, T. Sears, and N. Terry. 2000. Over-expression of glutathione reductase in *Brassica juncea*: Effects on cadmium accumulation and tolerance. *Physiolog. Plant.*, 110:455-460.
- Terry, N. 2000. The San Francisco Bay Constructed Wetland Treatment System: The Use of Constructed Wetland Treatment Systems for the Removal of Toxic Trace Elements from Electric Utility Wastewater: Role of Vegetation. EPRI, Palo Alto, CA: 2000. 1000269, pp. 1-48.
- Terry, N. September, 2000. Final Report on USDA-ATUT Project WM-01, "Water-Fertility Management for Subsurface Drip Irrigated Wheat and Faba Bean", pp. 1-87.
- Terry, Norman. November, 2000. Final Report on NSF-EGYPT, Project #: BIO3-004-004, "Development of Plant-Microbe Interactions for the Phytoremediation of Heavy Metals in Contaminated Environments", pp. 1-4.
- Terry, Norman. December, 2000. Final Report on NSF-SGER Award #9900054, "Genetic Modification of Plants to Increase Their Capacity for the Removal of Se from Contaminated Soil", pp. 1-50.
- Lin, Z.-Q. and N. Terry. 2000. Use of flow-through constructed wetlands for the remediation of selenium in agricultural tile-drainage water. Salinity/Drainage Program, Report 96-7. Center for Water Resources, University of California, Riverside, California. p. 192-227.
- Lin, Z.-Q. de Souza, M. and N. Terry. 2000. Evaluation of the macroalga, *Chara*, for remediation of Se-contaminated agricultural drainage water. Salinity/Drainage Program, Report 98-4. Center for Water Resources, University of California, Riverside, California. Pp. 173-191.

- Pilon-Smits, E.A.H., Y.L. Zhu, and N. Terry. 2000. Improved metal phytoremediation through plant biotechnology. *Tailings and Mine Waste '00*, Rotterdam., pp. 317-320.
- Terry, N. 2000. Proceedings of SOILREM 2000, The International Conference on Soil Remediation, Hangzhou, China, October 2000. "Phytoremediation of Se in Soil and Water", pp. 1-6.
- Whiting, S.N., M.P. de Souza, and N. Terry. 2001. Rhizosphere bacteria mobilize Zn for hyperaccumulation by *Thlaspi caerulescens*. *Environ. Sci. Technol.*, 35:3144-3150.
- Hale, K.L., S. McGrath, E. Lombi, S. Stack, N. Terry, I.J. Pickering, G.N. George, and E.A.H. Pilon-Smits. 2001. Molybdenum sequestration in *Brassica*: A role for anthocyanins? *Plant Physiol.*, 126:1391-1402.
- Ye, Z., S.N. Whiting, Z.Q. Lin, C.M. Lytle, J.H. Qian, and N. Terry. 2001. Removal and distribution of Fe, Mn, Co and Ni within a Pennsylvania constructed wetland treating coal combustion by-product leachate. *J. Environ. Qual.*, 30:1464-1473.
- Lee, A., Z.Q. Lin, I. Pickering, and N. Terry. 2001. X-ray absorption spectroscopy study shows that the rapid selenium volatilizer, pickleweed (*Salicornia bigelovii* Torr.) reduces selenate to organic forms without the aid of microbes. *Planta*, 213:977-980.
- de Souza, M.P., A. Amini, M.A. Dojka, I.J. Pickering, S.C. Dawson, N.R. Pace, and N. Terry. 2001. Identification and characterization of bacteria in a selenium-contaminated hypersaline evaporation pond. *Appl. Environ. Microbiol.* 67:3785-3794.
- Ye, Z.H., S.N. Whiting, J.H. Qian, C.M. Lytle, Z.-Q. Lin, and N. Terry. 2001. Trace element removal from coal ash leachate by a 10-year old constructed wetland. *Journal of Environmental Quality*, 30:1710-1719.
- Terry, N. 2001. Phytoremediation of Trace Elements by Wetland Plants, EPRI, Palo Alto, CA: 2001. 1005185, pp. 1-42.
- Terry, N. 2001. The Allegheny Power Services Constructed Wetland at Springdale: The Role of Plants in the Removal of Trace Elements. EPRI, Palo Alto, CA:2001. 1006504, pp. 1-46.
- Terry, N. 2001. Speciation of Trace Elements in Biological and Environmental Samples by X-ray Absorption Spectroscopy: The Role of Plants and Microbes in Remediation, EPRI, Palo Alto, CA: 2001. 1006507, pp. 1-59.
- Terry, N. 2001. Use of flow-through constructed wetlands for the removal of selenium in agricultural tile-drainage water. In: U.C. Salinity/Drainage Task Force, Division of Agriculture and Natural Resources, University of California (Annual Report for 2000-2001).
- Terry, N. 2001. Final Report to the U.S.-Egypt Joint Science and Technology Board (NSF Award # 9904790). "Development of Plant-Microbe Interactions for the Phytoremediation of Heavy Metals in Contaminated Environments". Dec. 31, 2001.
- Terry, N. 2001. Final Report for NSF-SGER Proposal: "Genetic Modification of Indian Mustard to Increase Its Capacity for Removal of Selenium from Contaminated Soil" (Award # 9900054), Dec. 31, 2001.
- Terry, N. Final Report for NSF Proposal: "Molecular aspects of selenium hyperaccumulation and volatilization in plants" (Award # 9904643), Dec. 31, 2001 (1-23 pp).
- Terry, N. 2001. Proceedings of the Sixth International Conference on the Biogeochemistry of Trace Elements, Guelph, Canada, July 29-August 2, 2001. "Phytoremediation of Selenium and Other Trace Elements in Soil and Water".

- Lin, Z.-Q., Cervinka, V., Pickering, I. J., Zayed, A., and Terry, N. 2002. Managing selenium-contaminated agricultural drainage water by the integrated on-farm drainage management system: Role of selenium volatilization. *Water Research* 36: 3150-3160.
- de Souza, M.P., Pickering, I.J., Walla, M., and Terry, N. 2002. Selenium assimilation and volatilization from selenocyanate-treated Indian mustard and muskgrass. *Plant Physiol.* 128:625-33.
- Lin, Z.Q., de Souza, M., Pickering, I.J., and Terry, N. 2002. Evaluation of the macroalga, muskgrass, for the phytoremediation of selenium-contaminated agricultural drainage water by microcosms. *J. Environ. Qual.* 31:2104-10
- Berken, A., Mulholland, M.M., LeDuc, D.L. and Terry, N. 2002. Genetic engineering of plants to enhance selenium phytoremediation. *Crit. Rev. Plant Sci.* 21:567-582.
- Fox, P.M., D.L. LeDuc, H. Hussein, Z.-Q. Lin, and N. Terry. 2002. Selenium speciation in soils and plants. In: Y. Cai and O. Braids, eds., *Biogeochemistry of Environmentally Important Trace Elements*. ACS Symposium Series. p. 339-354.
- Hale, K.H., Tufan, H.A., Pickering, I.J., George, G.N., Terry, N., Pilon, M., Pilon-Smits, E.A.H. 2002. Anthocyanins facilitate tungsten accumulation in *Brassica*. *Physiol. Plantarum*. 116:351-358.
- Douclev, M. and Terry, N. 2002. Pumping out the arsenic. *Nat. Biotechnol.* 20:1094-5 (Invited article which was peer reviewed).
- Meija, J., M. Montes-Bayon, D.L. LeDuc, N. Terry, and Caruso, J.A. 2002. Simultaneous monitoring of volatile selenium and sulfur species from Se accumulating plants (wild-type and genetically modified) by GC-MS and GC-ICP-MS using SPME for sample introduction. *Anal. Chem.* 74:5837-44.
- Montes-Bayon, M., D.L. LeDuc, N. Terry, and Caruso, J.A. 2002. Selenium speciation in wild-type and genetically modified Se accumulating plants with HPLC separation and ICP-MS/ES-MS detection. *J. Anal. Atomic Spectrom.* 17:872-879.
- Tagmount, A., Berken, A., and Terry, N. 2002. An essential role of S-adenosyl-L-methionine:methionine S-methyltransferase in selenium volatilization by plants: Methylation of selenomethionine to Se-methyl-L-Se-methionine, the precursor of volatile Se. *Plant Physiol.* 130:847-856.
- De Souza, M. and N. Terry. 2002. Remediation of Selenium and Other Trace Elements by Free-Living and Plant-Associated Microbes. Final Report, February 2002. EPRI Report, Palo Alto, CA: 2002. TR-114220. pp. 1-102.
- Terry, N. 2002. Improving the Efficiency of Metal Phytoremediation: Identification and Genetic Engineering of a Novel Regulator Gene Controlling Plant Responses to Stress. Fourth EPRI Report, February 28, 2002.
- Hussein, H. and N. Terry. 2002. Phytoremediation of PAH- and PCB-Contaminated Soils. Status Report on EPRI Grant No.: EP-P7324/C3725 September 4, 2002.
- Lin, Z.-Q., P. D. LeDuc, H. Hussein, and N. Terry. 2002. Significance of Selenium Volatilization in Wetlands Treating Se-laden Agricultural Drainage Water. Salinity/Drainage Program, Annual Report 00-17. Center for Water Resources, University of California, Riverside, CA. 21 pp.
- Banuelos, G.S., Lin, Z.Q., Wu, L., and Terry, N. 2002. Phytoremediation of selenium-contaminated soils and waters: fundamentals and future prospects. *Rev. Environ. Health.* 17:291-306.

Hussein, H.S. and Terry, N. 2002. Phytomonitoring the unique colonization of oil-contaminated saline environment by *Limoniastrum monopetalum* (L.) Boiss in Egypt. *Environ. Int.* 28:127-135.

Terry, N. 2002. Proceedings of the International Workshop 2002 (Mobility in Biosphere of Iodine, Technetium, Selenium and Uranium) organized by Andra (French national Radioactive Waste Management Agency), and IUR (International Union of Radioecologists), Nancy, France – April 3-5, 2002. "Selenium Speciation in Soils and Plants and Its Potential Role in Phytoremediation".

Terry, N. 2002. Proceedings of the 5th Workshop on Sulfur Assimilation in Higher Plants, Montpellier, France, April 11-14, 2002. "Selenium - The Black Sheep of the Sulfur Family!"

Terry, N. 2002. Proceedings of the Sixth International Symposium on Environmental Biotechnology and Fourth International Symposium on Cleaner Bioprocesses and Sustainable Development, June 9-12, 2002, Veracruz, Mexico. "Phytoremediation of Heavy Metals and Metalloids: Studies from the Molecular to the Field Level".

Terry, N. 2002. Proceedings of the 12<sup>th</sup> International Biodeterioration and Biodegradation Symposium, Prague, Czech Republic July 14-18, 2002. "Phytoremediation of Trace Elements from the Molecular to the Field Level".

Terry, N. 2002. Proceedings of the 17th World Congress on the Soil Science (Phytoremediation Symposium) Bangkok, Thailand Conference – August 21, 2002. "Phytoremediation of Selenium and Other Trace Elements in Soil and Water".

Terry, N. 2002. Proceedings of the 9<sup>th</sup> New Phytologist Symposium, Heavy Metals and Plants from Ecosystems to Biomolecules, University of Pennsylvania, Philadelphia, October 1, 2002. "Phytoremediation of Heavy Metals from the Molecular to the Field Level: Possible Roles for Phytochelatin and Other Cellular Components".

Zayed, A.M. and Terry, N. 2003. Chromium in the environment: factors affecting biological remediation. *Plant and Soil*. 249:139-156.

Aviles, C., Loza-Tavera, H., Terry, N., and Moreno-Sanchez, R. 2003. Mercury pretreatment selects an enhanced cadmium-accumulating phenotype in *Euglena gracilis*. *Arch. Microbiol.* 180:1-10.

Bennett, L.E., Burkhead, J.L., Hale, K.L., Terry, N., Pilon, M., and Pilon-Smits, E.A. 2003. Analysis of transgenic Indian mustard plants for phytoremediation of metal-contaminated mine tailings. *J. Environ. Qual.* 32:432-440.

Gao, S., Tanji, K.K., Lin, Z.Q., Terry, N., and Peters, D.W. 2003. Selenium removal and mass balance in a constructed flow-through wetland system. *J. Environ. Qual.* 32:1557-1570.

Gao, S., K.K. Tanji, D.W. Peters, Z.-Q. Lin, and N. Terry. 2003. Selenium removal from irrigation drainage water flowing through constructed wetland cells with special attention to accumulation in sediments. *Water, Air and Soil Pollution* 1: 263-284.

Lin, Z.Q. and Terry, N. 2003. Selenium removal by constructed wetlands: quantitative importance of biological volatilization in the treatment of selenium-laden agricultural drainage water. *Environ. Sci. Technol.* 37:606-615.

Neumann, P.M., de Souza, M.P., Pickering, I.J., and Terry, N. 2003. Rapid microalgal metabolism of selenate to volatile dimethylselenide. *Plant Cell Environ.* 26:897-905.

Ruiz, O.N., Hussein, H.S., Terry, N., and Daniell, H. 2003. Phytoremediation of organomercurial compounds via chloroplast genetic engineering. *Plant Physiol.* 132:1344-1352.

- Van Huysen, A., Abdel-Ghany, S., Hale, K.L., LeDuc, D., Terry, N., and Pilon-Smits, E.A. 2003. Overexpression of cystathionine-gamma-synthase enhances selenium volatilization in *Brassica juncea*. *Planta* 218:71-78.
- Ye, Z.H., Lin, Z.Q., Whiting, S.N., de Souza, M.P., and Terry, N. 2003. Possible use of constructed wetland to remove selenocyanate, arsenic, and boron from electric utility wastewater. *Chemosphere* 52:1571-9.
- Terry, N., Sambukumar, S.V., LeDuc, D.L. 2003. Biotechnological approaches for enhancing phytoremediation of heavy metals and metalloids. *Acta Biotechnologica*, 23:281-288 (Invited article which was peer reviewed).
- LeDuc, D.L. and Terry, N. 2003. Physiological and environmental significance of selenium. In *Sulfur Transport and Assimilation in Plants. Regulation, Interaction, and Signaling*. Eds. J.-C. Davidian, D. Grill, L.J. DeKok, I. Stulen, M.J. Hawkesford, E. Schnug, and H. Rennenberg. pp. 79-89. Backhuys Publishers, Leiden, The Netherlands. (Invited article which was peer reviewed).
- Nakayama, H. and N. Terry. 2003. Novel Strategies to Develop Heavy Metal, Plant Pathogen, and Insect Resistant Transgenic Plants for Phytoremediation. EPRI, August 1, 2003. (EPRI Grant proposal entitled: Genetic Engineering of Novel Genes to Generate Transgenic Plants with Superior Potential for Phytoremediation and Pathogen Defense).
- Tagmount, M. and N. Terry. 2003. Developing Heavy Metal and/or Oxidative Stress Resistant Transgenic Plants by Overexpressing Genes Identified by Complementation of the Yeast yap1 Mutant. EPRI Report, August 2003. (EPRI Grant proposal entitled: Genetic Engineering of Novel Genes to Generate Transgenic Plants with Superior Potential for Phytoremediation and Pathogen Defense).
- LeDuc, D., V. Sambukumar, and N. Terry. 2003. Enhancing Phytoremediation through Promoter Analysis. Identification of *cis*-elements and corresponding transcriptional factors in response to heavy metal stress and S-starvation. EPRI Report, September 2003. (EPRI Grant proposal entitled: Genetic Engineering of Novel Genes to Generate Transgenic Plants with Superior Potential for Phytoremediation and Pathogen Defense).
- Terry, N. and Y. Chang. 2003. Phytoremediation of Selenium-Contaminated Drainage Sediments and Chemical Characterization of Potentially Ecotoxic Selenium Forms. UC Salinity/Drainage Program, Annual Report. Center for Water Resources, University of California, Riverside, CA. 19 pp.
- Terry, N. 2003. Proceedings of the US EPA International Applied Phytotechnologies Conference, March 4, 2003. "Phytoextraction and Phytovolatilization of Selenium from Selenium-Contaminated Environments".
- Lin, Z.-Q., H. Hussein, A. Tagmount, A. Lee, and N. Terry. 2003. Pickleweed: a novel species for the phytoremediation of selenium. 1(2): 172-173. In: G.R. Gobran and N. Lepp (eds.), Proceedings of the 7th International Conference on the Biogeochemistry of Trace Elements, June 15-19, 2003, Sweden (ISBN 91-576-6582-6).
- Bañuelos, G. Z.-Q. Lin, N. Terry, and I. Arroyo. 2003. Managing toxic levels of soluble selenium in drainage sediment with phytoremediation. 1(2): 128-129. In: G.R. Gobran and N. Lepp (eds.), Proceedings of the 7th International Conference on the Biogeochemistry of Trace Elements, June 15-19, 2003, Sweden (ISBN 91-576-6582-6).
- Lin, Z.-Q., N. Terry, T.Q. Zhang, S. Lipe, and H. Mohamed. 2003. Chemical behavior of environmentally important elements: speciation analysis by X-ray absorption spectroscopy (XAS). 49th International Conference on Analytical Sciences and Spectroscopy, 1-4 June 2003, Ottawa, Canada.
- Grant, T.D., Montes-Bayon, M., LeDuc, D., Fricke, M.W., Terry N., and Caruso, J.A. 2004. Identification and characterization of Se-methyl selenomethionine in *Brassica juncea* roots. *Journal of Chromatography A*. 1026:159-166.

LeDuc, D.L., Tarun, A.S., Montes-Bayón, M., Meija, J., AbdelSamie, M., Wu, C.P., Malit, M.F., Chang, C.-Y., Tagmount, A., de Souza, M., Neuhierl, B., Böck, A., Caruso, J., and Terry, N. 2004. Overexpression of Selenocysteine Methyltransferase in *Arabidopsis thaliana* and *Brassica juncea* Increases Selenium Tolerance and Accumulation. *Plant Physiology* 135:384-399.

T. Van Husen, N. Terry, and E. A. H. Pilon-Smits. 2004. Exploring the selenium phytoremediation potential of transgenic Indian mustard overexpressing ATP sulfurylase or cystathionine- $\gamma$ -synthase. *International Journal of Phytoremediation* 6:111-118.

Wangelin AL, Burkhead JL, Hale KL, Lindblom S-D, Terry N, Pilon M, Pilon-Smits EAH (2004) Overexpression of ATP Sulfurylase in *Brassica juncea*: Effects on Tolerance and Accumulation of Twelve Metals. *Journal of Environmental Quality* 33: 54-60

Terry, N. and Y. Chang. 2004. Phytoremediation of Selenium-Contaminated Drainage Sediments with Different Transgenic Lines of Indian Mustard (*Brassica juncea*). UC Salinity/Drainage Program, Annual Report, pp. 45-52. Center for Water Resources, University of California, Riverside, CA. 21 pp

Hussein, H. and N. Terry. 2004. Phytoremediation of PAH- and PCB-Contaminated Soils. Interim Report on EPRI Grant No.: EP-P7324/C3725, June, 2004.

Terry, N. 2004. Proceedings of the 7<sup>th</sup> Biennial Symposium of the International Society of Environmental Biotechnology, Chicago, June 18-21, 2004. "Phytoremediation of Toxic Trace Elements in Soil and Water".

Bañuelos, G., Terry, N., LeDuc, D., Pilon-Smits, E.A.H., and Mackey, B. Field trial of transgenic Indian mustard plants shows enhanced phytoremediation of selenium-contaminated soil. *Environ. Sci. Technol.*, 2005:1771-1777.

Terry, N. and LeDuc, D. 2005. Phytoremediation of selenium and other toxic trace elements. International Society of Environmental Botanists Archive. Reproduced from Third International Conference on Plants & Environmental Pollution (ICPEP-3) held at Lucknow from 28 November to 2 December 2005 (invited review).

Hussein, H. and N. Terry. 2005. Phytoremediation of PAH- and PCB-Contaminated Soils. Final Report. EPRI Grant No.: EP-P7324/C3725. January 5, 2005.

LeDuc, D.L. and Terry, N. 2005. Phytoremediation of Toxic Trace Elements in Soil and Water. *J. Industrial Microbiology and Biotechnology*, 32:514-520.

Bañuelos, G.S., Z.-Q. Lin, I. Arroyo, and N. Terry. 2005. Selenium volatilization in vegetated agricultural drainage sediment from the San Luis Drain, Central California. *Chemosphere*, 60:1203-1213.

LeDuc, D.L. and Terry, N. 2005. Genetic engineering stress tolerant plants for phytoremediation. In: *Abiotic Stress Tolerance in Plants*. Eds. A.K. Rai and T. Takabe. Springer, Dordrecht, The Netherlands.

Terry, N. 2005. Proceedings of the 17th Annual Association for Environmental and Health Sciences (AEHS) Meeting & West Coast Conference on Soils, Sediments and Water, March 19th - 22nd, 2005, Marriott Mission Valley, San Diego, California. "Phytoremediation of Selenium and Other Toxic Trace Elements" (invited paper).

Terry, N. 2005. Proceedings of the 8<sup>th</sup> International Conference on the Biogeochemistry of Trace Elements, 3 - 7 April 2005, Adelaide, Australia. "Overexpressing Both ATP Sulfurylase and Selenocysteine Methyltransferase Enhances Selenium Phytoremediation by Indian Mustard" (invited paper).

Terry, N. 2005. Proceedings of the 10<sup>th</sup> Congress of the Brazilian Society of Plant Physiology and the XII Latin American Congress on Plant Physiology (Uruguay, Argentina, Brazil and Chile), 11-16<sup>th</sup> September 2005 in Recife, Brazil. "Phytoremediation of Toxic Trace Elements from the Molecular to the Field Scale" (invited paper).

Terry, N. 2005. Proceedings of the Third International Conference on Plants and Environmental Pollution (ICPEP-3), 28 November - 2 December, 2005, at National Botanical Research Institute, Lucknow, India. "Phytoremediation of Selenium and Other Toxic Trace Elements" (invited plenary lecture).

Terry, N. 2005. Proceedings of the Satellite Session, Medicinal Plants and Environmental Pollution, December 4, 2005, at Hamdard University, New Delhi, India. "The use of plant-based systems for cleaning up polluted environments" (invited lecture).

LeDuc, D.L., AbdelSamie, M., Montes-Bayon, M., Wu, C.P., Reisinger, S.J., and Terry, N. 2006. Overexpressing both ATP sulfurylase and selenocysteine methyltransferase enhances selenium phytoremediation traits in Indian mustard. *Environ. Pollution*, 144:70-76.

Navaza, A.P., Montes-Bayon, M., LeDuc, D.L., Terry, N., and Sanz-Medel, A. 2006. Study of phytochelatins and other related thiols as complexing biomolecules of As and Cd in wild type and genetically modified *Brassica juncea* plants. *J. Mass Spectrometry*, 41:323-331.

Lindblom SD, Abdel-Ghany SE, Hanson BR, Hwang S, Terry N, Pilon-Smits EAH. 2006. Constitutive expression of a high-affinity sulfate transporter in *Brassica juncea* affects metal tolerance and accumulation. *J. Environ. Quality*, 35: 726-733.

Terry, N. 2006. Proceedings of the International Symposium on Trace Elements in the Food Chain (TEFC) Budapest, Hungary, May 25-27, 2006. "Phytoremediation of Selenium and Other Toxic Trace Elements" (invited paper).

Bañuelos, G., LeDuc, D., Pilon-Smits, E.A.H., and Terry, N. 2007. Transgenic Indian mustard overexpressing selenocysteine lyase or selenocysteine methyltransferase exhibit enhanced potential for selenium phytoremediation under field conditions. *Environ. Sci. Technol.*, 41:599-605.

Kubachka, K.M., Meija, J., LeDuc, D.L., Terry, N., and Caruso, J.A. 2007. Selenium volatiles as proxy to the metabolic pathways of selenium in genetically modified *Brassica juncea*. *Environ. Sci. Technol.*, 41:1863-1869.

Hussein, S. Hussein, Oscar N. Ruiz, Norman Terry, and Henry Daniell. 2007. Phytoremediation of mercury and organomercurials in chloroplast transgenic plants: enhanced root uptake, translocation to shoots, and volatilization. *Environ Sci Technol.*, 41:8439–8446.

Kassis, E. E., N. Cathala, H. Rouached, P. Fourcroy, P. Berthomieu, N. Terry and J-C. Davidian, 2007. Characterization of a Selenate-Resistant Arabidopsis Mutant. Root Growth as a Potential Target for Selenate Toxicity. *Plant Physiol.*, 143:1231–1241.

Lin, Z.-Q., H. Mohamed, Z.H. Ye, and N. Terry. 2007. Phytoremediation of metal-contaminated industrial wasteland: a greenhouse feasibility study. In: D. Sarkar, R. Datta, and R. Hannigan (eds.), *Concepts and Applications in Environmental Geochemistry*. Elsevier, Amsterdam, The Netherlands. 487-502.

Reisinger S, Schiavon M, Terry N, Pilon-Smits EAH. 2008. Heavy metal tolerance and accumulation in Indian mustard (*Brassica juncea* L.) overexpressing bacterial g- glutamylcysteine synthetase or glutathione synthetase. *Int. J. Phytoremediation*, 10: 440-454

- Z.-Q. Lin, N. Terry, S. Gao, and Z.H. Ye. 2008. Vegetation changes and role of plants in partitioning selenium in 4-year old constructed wetlands treating agricultural drainage. Proceedings of 5th International Conference on Phytotechnologies. 22-24 October 2008. Nanjing, China.
- Z.-Q. Lin, N. Terry, S. Gao, S. Mohamed, Z.H. Ye. 2009. Vegetation changes and partitioning of selenium in 4-year-old constructed wetlands treating agricultural drainage. *Int. J. Phytoremediation*, in press.
- Stiles, A.R., Bautista, D., Atalay, E., Babaoğlu, M., Terry N., 2010. Mechanisms of Boron Tolerance and Accumulation in Plants: A Physiological Comparison of the Extremely Boron-Tolerant Plant Species, *Puccinellia distans*, with the Moderately Boron-Tolerant *Gypsophila arrostil*. *Environmental Science and Technology*, 44: 7089- 7095.
- Lin, Z.Q., N. Terry, S. Gao, S. Mohamed, Z.H. Ye. 2010. Vegetation changes and partitioning of selenium in 4-year-old constructed wetlands treating agricultural drainage. *International Journal of Phytoremediation*, 12: 255-267.
- Huang, JC, Verce, MV, Stiles, A., Terry, N., 2010. Development of a Constructed Wetland Water Treatment System for the Salton Sea Species Conservation Habitat – A Review. *Report prepared for the California Department of Water Resources Salton Sea Species Conservation Habitat Project*. August 29, 2010.
- Stiles AR, Liu C, Kayama Y, Wong J, Doner H, Funston R, Terry N. 2011. Evaluation of the boron tolerant grass, *Puccinellia distans*, as an initial vegetative cover for the phytoremediation of a boron-contaminated mining site in Southern California. *Environ Sci Technol.*, 45: 8922-7.
- Matthew F. Verce, Amanda R. Stiles, Karen C. Chong, Norman Terry. 2012. Isolation of an extremely boron-tolerant strain of *Bacillus firmus*. *Canadian Journal of Microbiology*, 58(6): 811-814.
- Priya Padmanabhan, Mehmet Babaoğlu and Norman Terry. 2012. A comparative transcriptomic analysis of the extremely boron tolerant plant *Puccinellia distans* with the moderately boron tolerant *Gypsophila arrostil*". *Plant Cell Reports*, 31(8): 1407-1413
- Stiles, A.R., Liu, Ch., Tran, H., Liu, J., Funston, R., Terry, N. 2012. Boron-Tolerance of Native Mojave Desert Plant Species: Implications for the Phytoremediation of a Boron-Contaminated Mining Site. *Environmental Science and Technology (in preparation)*

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### ACADEMIC AND TEACHING EXPERIENCE

- Postdoctoral fellow in the Department of Plant and Microbial Biology at the University of California, Berkeley, CA USA, April 2010-Present
  - UC Berkeley Salton Sea Research Project
    - *Phytoremediation of selenium in wetland ecosystems at the Salton Sea, CA USA.*
- Research assistant and teaching assistant at the Olentangy River Wetland Research Park (ORWRP) at the Ohio State University, OH USA, September 2005-September 2009.
  - Living machine, OH USA, January 2006 - March 2006 (Class project)
    - *Design of an indoor living machine for wastewater treatment.*
  - Post-Hurricane Katrina Community plans for Pineville, MS, June 2007 -May 2007.
    - *Ecological planning for the downstream riparian area of Wolf River.*
  - Ecological restoration of Grave Creek on the Ohio State University Marion campus, OH, May 2007 - May 2008.
    - *Channel design for dechannelization of Grave Creek.*
    - *Design of a riparian wetland for research, teaching, conservation and river water quality improvement.*
  - Interactions between a stream channel and a riparian wetland, OH, December 2007 - May 2009.
    - *Design and construction of reconnection between a riparian wetland and an experimental channel at the ORWRP.*
    - *Simulation of natural flood pulses to restore wetland functions such as downstream water quality improvement.*
  - Effects of different channel forms on water quality and ecosystem structure, OH, October 2007 - May 2009.
    - *Design of three experimental streams for simulating headwater stream restoration at the ORWRP.*
- Research Assistant in Water Environment Research Center (WERC), NTUT, Taipei, Taiwan, Jan. 2003-May 2005.
  - The Application of Constructed Wetlands and Artificial Floating Islands in Kinmen,

- Taiwan, May 2004 -May 2005.
  - *Design and construction of a constructed wetland for wastewater treatment.*
  - *Design and construction of two artificial floating islands for wastewater treatment.*
- The Establishment of Ecological Engineering Parameters in Reservoir Watershed, Taiwan, March 2004 - May 2005.
  - *Design of a circular experimental channel for monitoring fish behavior.*
- Restoration of Neigou River, Taiwan, March 2004 - May 2005.
  - *Channel design for dechannelization of Neigou River through the urban area in Taipei.*
  - *Ecological design of riverbanks.*
  - *Design of a riparian wetland for river water quality improvement and species conservation.*
- Community Participation in Wetland Construction-A Case Study of Tatun and Masu communities, Taiwan, October 2003 - December 2003
  - *Design and construction of two wetlands for demonstration and species conservation.*
- The Watershed Management of the Masu River, Taiwan, February 2003 - November 2003.
  - *Design and construction of a series of wetlands for mine drainage water treatment.*
- The Establishment of Eco-park based on The Restoration of The Derelict Land. Case Study, Fu Bao Eco-Park, Taiwan, September 2000 - January 2003.
  - *Design and planning of coastal wetlands for migrating waterfowls.*
- Lecturer, National Open University, Taipei, Taiwan, February 2003 - July 2003.
- Substitute Teacher of Taipei County Tzyh Chang Junior High School, Taipei, Taiwan, February 2002 - July 2002.
- Coastal Habitat Manager, Taiwan Environmental Protection Union, Changhua, Taiwan, September 2001- May 2002.

## PRESENTATIONS AND PUBLISHED ABSTRACTS

Huang, J. C., 2010. Estimating interactions between a stream channel and a diversion wetland at the Olentangy River Wetland Research Park, Ohio USA. The Ecological Society of America Annual meeting. 1-8 August 2010, Pennsylvania, USA Pittsburgh.

Huang, J. C., 2009. Interactions between a stream channel and a riparian wetland at the Olentangy River Wetland Research Park, Ohio USA. 2009 Society of Wetland Scientists Annual meeting. 21-26 June 2009, Wisconsin, USA.

Huang, J. C., 2007. Ecological restoration of a stream on a college campus in central Ohio. Ecohydrological Processes and Sustainable Floodplain Management Opportunities and Concepts for Water Hazard Mitigation, and Ecological and Socioeconomic Sustainability. 19-23 May 2008, Lodz, Poland.

Huang, J. C., 2004. The Application of Artificial Floating Island in Kinmen. Islands of the World : Changing Islands- Changing Worlds. Kinmen, Taiwan. 2004.

## PUBLICATIONS

Huang, J. C., E. Passeport, N. Terry. 2012. Development of a constructed wetland water treatment system for selenium removal: use of mesocosms to evaluate design parameters. Environmental Science and Technology (*in press*).

Huang, J. C., W.J. Mitsch, and D.L. Johnson. 2011. Estimating biogeochemical and biotic interactions between a stream channel and a created riparian wetland: A medium-scale physical model. *Ecological Engineering* 37:1035–1049.

Huang, J. C., Verce, MV, Stiles, A., and Terry, N., 2010. Development of a Constructed Wetland Water Treatment System for the Salton Sea Species Conservation Habitat – A Review. *Report prepared for the California Department of Water Resources Salton Sea Species Conservation Habitat Project*. August 29, 2010.

Huang, J. C., W.J. Mitsch, and A.D. Ward, 2010. Design of experimental streams for simulating headwater stream restoration. *J. American Water Resources Association* 46: 957-971.

Zhang, L., and J. C. Huang. 2009. Ecological engineering for watershed ecosystem management in China. *Journal of Sichuan forestry science and technology* 30: 23-24. (in Chinese)

Huang, J. C., W. J. Mitsch, and L. Zhang. 2009. Ecological restoration of a stream on a college campus in central Ohio. *Ecological Engineering* 35: 329–340.

Cowley, J., B. Cowell, J. C. Huang, S. Das, R. Mathur, B. Warren, J. Washco, and A. Willis. 2007. Community Plan for Pineville, Harrison County, Mississippi. The Mississippi Department of Environmental Quality.

Chen, Y.-C., J.-Y. Lin, E.H. Tsao, J.-C. Huang. 2005. Minimum flow estimated by the Froude number. In: *World Water & Environmental Resources Congress 2005*, Anchorage.

Lin, J. Y., Y. C. Chen, and J. C. Huang. 2005. Community Participation in Wetland Construction-A Case Study of Tatun and Masu communities. Water Resources Bureau, Taiwan. *Sustainable Development Newsletter* 14: 20-25. (In Chinese)

Lin, J. Y., and J. C. Huang. 2004. BMPs for the Mine Drainage-A Case Study of the Clay Mine in the Masu River. *Journal of Taiwan Water Conservancy* 52: 39-48. (In Chinese)

## **HONORS AND AWARDS**

- Outstanding Award in the Contest of Planning of Chang Hua Coastal Industrial Park of Industrial Development Bureau, 2002.
  - *Design of coastal wetlands in the park for species conversation and environmental education.*
- Outstanding Award in the Contest of Revivification of the Historic Building in Taiwan of Council for Cultural Affairs, 2002.

## **RESEARCH FELLOWSHIPS**

- Young Scientists Summer Program (YSSP) Fellowship, The International Institute for Applied Systems Analysis (IIASA), 2008

# Soo In Yang

## *Curriculum vitae*

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### EDUCATION

<b>Ph.D. Geological Sciences</b>	<b>2011</b>
<i>University of Saskatchewan, Canada</i>	
<b>M.Sc. Applied Microbiology and Food Science</b>	<b>2007</b>
<i>University of Saskatchewan, Canada</i>	
<b>B.Sc. Biological Resources and Technology</b>	<b>2001</b>
<i>Yonsei University, South Korea</i>	

### RESEARCH EXPERIENCE

- Biotransformation and interactions of selenium with mixed and pure culture biofilms
- Cloning, expression, and characterization of lactic acid bacteria recombinant prolidases

### RESEARCH EXPERTISE

Microbiology; Enzymology; Gene cloning and expression; Confocal laser scanning microscopy (CLSM); Transmission electron microscopy (TEM); Synchrotron techniques including X-ray absorption spectroscopy (XAS), X-ray fluorescence imaging (XRF) and Scanning transmission X-ray microscopy (STXM).

### SYNCHROTRON TRAINING/EXPERIENCE

Six years experience at the Advanced Light Source (Berkeley, CA, USA; 4.0.2.), Advanced Photon Source (Argonne, IL, USA; 2-ID-D), Canadian Light Source (Saskatoon, SK, Canada; HXMA, SGM, SM), and Stanford Synchrotron Radiation Lightsource (Menlo Park, CA, USA; BL2-3, BL7-3, BL9-3, BL10-2).

### PUBLICATIONS

GS Bañuelos, SS Walse, SI Yang, IJ Pickering, SC Fakra, MA Marcus and JL Freeman (2012) Quantification, localization and speciation of selenium in seeds of canola and two mustard species compared to seed-meals produced by hydraulic press. *Analytical Chemistry*. 84: 6024-6030.

GS Bañuelos, C Stushnoff, SS Walse, T Zuber, SI Yang, IJ Pickering, and JL Freeman (2012) Bio-fortified, selenium enriched, fruit and cladode from three *Opuntia* Cactus pear cultivars grown on agricultural drainage sediment for use in nutraceutical foods. *Food Chemistry*. 135: 9-16.

SI Yang, JR Lawrence, IJ Pickering (2011) Biotransformation of selenium and arsenic in multi-species biofilm. *Environmental Chemistry*. 8: 543-551. *Selected as 'Highlight Issue' of year 2011.*

CF Quinn, CN Prins, AM Gross, RJB Reynolds, JL Freeman, SI Yang, PA Covey, GS Bañuelos, IJ Pickering, S Fakra, MA Marcus, PA Bedinger, HS Arathi and EAH Pilon-Smits (2011) Selenium accumulation in flowers and its effects on pollination. *New Phytologist*. 192: 727-737.

GS Bañuelos, SC Fakra, SS Walse, MA Marcus, SI Yang, IJ Pickering, EAH Pilon-Smits and JL Freeman (2011) Selenium accumulation, distribution and speciation in spineless prickly pear cactus: a drought and salt tolerant, Se enriched nutraceutical fruit crop for biofortified foods. *Plant Physiology*. 155: 315-327.

SI Yang, JR Lawrence and IJ Pickering (2010) Biotransformation of selenium in multispecies biofilm. *Geochimica et Cosmochimica Acta*. 74: A1176-A1176.

SI Yang, T Tanaka (2008) Characterization of recombinant prolidase from *Lactococcus lactis*– changes in substrate specificity by metal cations, and allosteric behaviour of the peptidase. *FEBS Journal*. 275: 271-280.

SI Yang, GN George, JR Lawrence, JJ Dynes, SGW Kaminskyj and IJ Pickering (2012) Multispecies biofilms biotransform selenium oxyanions into nano particles. *Proceedings of the National Academy of Sciences*. In preparation.

R Schmidt, KR Hristova, P Tantoyotai, SC Fakra, MA Marcus, SI Yang, IJ Pickering, GS Bañuelos and JL Freeman (2012) Selenium bioaccumulation and biotransformation inside a constructed aquatic ecosystem for agriculture drainage water remediation and Se-enriched brine shrimp production. *PLoS One*. In preparation.

#### **PRESENTATIONS (INTERNATIONAL CONFERENCES)**

IJ Pickering\*, MG Gallegos, JJ Tse, SI Yang, GN George (2011). Synchrotron studies of selenium in the environment and health. Invited keynote oral presentation, *Second International Conference on Selenium in the Environment and Human Health*. Suzhou, China.

IJ Pickering\*, M Korbas, TC MacDonald, MJ Pushie, JJ Tse, SI Yang, GN George, I Coulthard (2011). From anatomic to atomic: Synchrotron imaging and speciation of inorganic elements from the environment to human health. Keynote oral presentation, Metal Toxicity and Resistance, *Fifteenth International Conference on BioInorganic Chemistry (ICBIC-15)*. Vancouver, Canada.

SI Yang\*, GN George, JR Lawrence, JJ Dynes, B Lai, SGW Kaminskyj, IJ Pickering (2011). Selenium biotransformation in biofilm: An approach using synchrotron based hard and soft X-ray imaging techniques. Poster presentation. *Applied and Environmental Microbiology-Functional Interactions from Molecules to Biomes, Gordon Research Conference*. July, South Hadley, MA, USA.

IJ Pickering\*, SI Yang, JR Lawrence, JJ Dynes, SGW Kaminskyj and GN George (2011) Synchrotron studies of selenium sequestration in biofilms. Invited oral presentation. *Georgian Bay International Conference on Bioinorganic Chemistry*. May, Parry Sound, ON, Canada.

SI Yang\*, JR Lawrence, SGW Kaminskyj, IJ Pickering (2010) Biotransformation of selenium in multispecies biofilms. Oral presentation. *Goldschmidt Conference*. June, Knoxville, TN, USA.

SI Yang\*, T Tanaka (2007) Soluble expression and characterization of recombinant proline-specific metalloprotease from *Lactococcus lactis*. Poster presentation. *American Society for Microbiology General Meeting*. May, Toronto, ON, Canada.

\*Presenting author

## INVITED PRESENTATIONS

SI Yang (2011) Biofilms biotransform selenium oxyanions. Oral presentation (invited). *Canadian Light Source Annual Users' Meeting*. June, Saskatoon, SK, Canada.

SI Yang (2010) Biotransformation of selenium in multispecies biofilms. Oral presentation (invited). *Canadian Institute of Health Research-Training Grant in Health Research Using Synchrotron Techniques (CIHR-THRUST)*. June, Saskatoon, SK, Canada.

## SELECTED RECENT SYNCHROTRON GENERAL USER PROPOSALS (AWARDED)

Advanced Photon Source (APS), Argonne, IL, USA, 2-ID-D beamline proposal: 18 shifts (144 hours) of beamtime were allocated with 'extraordinary scientific rate' (spokesperson: Soo In Yang, year 2010, proposal ID 21188); co-investigators: Ingrid J. Pickering, John R. Lawrence, and Susan G.W. Kaminskyj.

Canadian Light Source (CLS), Saskatoon, SK, Canada, SM beamline proposal: 6 shifts (48 hours) of beamtime were allocated with 'excellent scientific score' (spokesperson: Soo In Yang, year 2010, proposal ID 12-2677); co-investigators: Ingrid J. Pickering, John R. Lawrence, and Susan G.W. Kaminskyj.

**María Cristina Suárez Rodríguez**  
***Curriculum vitae***

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**EDUCATION**

<b>Ph.D. Plant Breeding and Plant Genetics</b>	<b>2007</b>
<i>University of Wisconsin, Madison.</i>	
<b>M.Sc in Developmental Biology</b>	<b>2002</b>
<i>California State University, Fresno.</i>	
<b>B.Sc. in Biological Sciences</b>	<b>1998</b>
<i>Universidad Nacional de Colombia-Bogotá.</i>	

**RESEARCH EXPERIENCE**

Postdoctoral scholar at University of California- Berkeley. Phytoremediation of Boron contaminated wastewater from electric utility power plants. Phytoremediation of the Rio Tinto BORAX mining site. Department of Plant and Microbial Biology

Postdoctoral scholar at the University of Copenhagen. ERA-ERPG Consortium for Multi-stress studies in *Arabidopsis thaliana*. Annotator-curator of MAPK signaling components in the *Selaginella moellendorffii* genome. Pyrosequencing the transcriptome of *Craterostigma plantagineum* a model for plants desiccation tolerance. *Pseudomonas* and *Botrytis* pathogenicity testing in *Arabidopsis* mutants.

Doctoral Studies in Plant Breeding and Plant Genetics as a Research Assistant in the Horticulture Department of the University of Wisconsin, Studies of plant stress signaling.

Research Assistant in the Biology Department of CSUFresno, Programmed Cell Death in *Arabidopsis thaliana*.

Research Assistant in the Cassava Genetics Unit of CIAT (International Center for Tropical Agriculture, Cali Colombia), Cassava Genetics of Agronomic Traits.

Bachelor's Internships in "Microbiological, biochemical and molecular characterization of Colombian native strains of *Bacillus thuringiensis*". "Isolation of the capsidic protein of Banana Streak Virus" (Colombian Corporation for agricultural research, CORPOICA, its Spanish acronym)

## PUBLICATIONS

Suárez, M.C., Bernal, A., Gutiérrez, J., Tohme, J., Fregene, M. (2000). Developing Expressed sequence tags (ESTs) from polymorphic transcript-derived fragments (TDFs) in cassava *Manihot esculenta* Crantz. Genome. 43,1. 62-67.

Fregene M., E. Okogbenin, C. Mba, F. Angel, Maria Cristina Suárez, Gutierrez Janneth, P. Chavarriaga, W. Roca, M. Bonierbale, and J. Tohme (2001). Genome Mapping in Cassava Improvement: Challenges, Achievements and Opportunities. Euphytica 120, 1 p. 159 - 165

Fregene MA, Suarez M, Mkumbira J, Kulembeka H, Ndedya E, Kulaya A, Mitchel S, Gullberg U, Rosling H, Dixon AG, Dean R, Kresovich S. (2003) Simple sequence repeat marker diversity in cassava landraces: genetic diversity and differentiation in an asexually propagated crop. Theor Appl Genet. Oct;107(6):1083-93.

Suarez-Rodriguez MC, L Adams-Phillips, Y Liu, H Wang, S Su, PJ Jester, S Zhang, AF Bent, and PJ Krysan. (2007). MEKK1 is required for flg22-induced MPK4 activation in *Arabidopsis* plants. Plant Physiol. 2007 Feb;143(2):661-9. Epub 2006 Dec 1

Su SH, Suarez-Rodriguez MC, Krysan P. (2007) Genetic interaction and phenotypic analysis of the *Arabidopsis* MAP kinase pathway mutations *mekk1* and *mpk4* suggests signaling pathway complexity. FEBS Lett. 2007 Jul 10;581(17):3171-7.

Qiu JL, Fiil BK, Petersen K, Nielsen HB, Botanga CJ, Thorgrimsen S, Palma K, Suarez-Rodriguez MC, Sandbech-Clausen S, Lichota J, Brodersen P, Grasser KD, Mattsson O, Glazebrook J, Mundy J, Petersen M. (2008) *Arabidopsis* MAP kinase 4 regulates gene expression through transcription factor release in the nucleus.. EMBO J. Aug 20;27(16):2214-21.

Rodriguez MC, Edsgard D, Rasmussen M, Gilbert T, Nielsen HB, Mundy J, Bartels D (2010) Transcriptomes of the desiccation tolerant resurrection plant *Craterostigma plantagineum*. Plant Journal Jul;63(2):212-28.

Maria Cristina Suarez Rodriguez, Morten Petersen, and John Mundy (2010) Mitogen-Activated Protein Kinase Signaling in Plants. Annu. Rev. Plant Biol. Vol. 61: 621-649.

### Meeting talks:

PBD Plant Biotech in Denmark Feb. 2008. The MPK4 Map kinase cascade in plant innate immunity in *Arabidopsis*

PBD Plant Biotech in Denmark Feb. 2009. Pyrosequencing transcriptomes from ancient maize and resurrection plants

### Poster presentations:

Suárez, M.C., Bernal, A., Gutiérrez, J., Tohme, J., Fregene, M. 1999. Developing Expressed sequence tags (ESTs) from polymorphic transcript-derived fragments (TDFs) in cassava (*Manihot esculenta* Crantz). Inauguration of the Latin American association for cassava. CIAT 1999

Maria Cristina Suarez R., Peter Jester, Patrick Krysan. 2005 Reverse Genetics Analysis of the *Arabidopsis* MapKinase Kinase Kinase *AtMEKK1*. 16<sup>th</sup> International Conference in *Arabidopsis* Research 2005.

Maria Cristina Suarez, Lori Adams-Phillips, Shih-Heng Su, Peter Jester, Andrew Bent, Patrick Krysan. MEKK1 is a Negative Regulator of Stress Responses in *Arabidopsis*, but this Function does not Require the Protein's Kinase Activity. 17<sup>th</sup> International Conference on *Arabidopsis* Research 2006.

Maria Cristina Suarez-Rodriguez, Lori Adams-Phillips, Yidong Liu, Huachun Wang, Shih-Heng Su, Peter J. Jester, Shuqun Zhang, Andrew F. Bent, and Patrick J. Krysan. MEKK1 kinase impaired mutant suggests a scaffolding function that is required for MPK4 activation in Arabidopsis. Twenty-Fourth Annual Missouri Plant Bio Symposium Plant Protein Phosphorylation-Dephosphorylation. May 22-24, 2007.

### **TEACHING EXPERIENCE**

Instructor at the training course of molecular techniques applied to the Identification of disease resistance in crops. CIAT. Cali. Colombia

Teaching associate in the course Bio10. Biology Department CSUFresno.

Instructor in Genetics and Gene tagging Laboratory. Plant Molecular Biology course University of Copenhagen.

### **AWARDS**

Honored Undergraduate Thesis. 1998

ERPG Reaserch Grant from the Student Association of California State University at Fresno. 2002.

#### ***Attachment 4. Work Plan (refers to schedule and budget attachments below)***

Scope of work: The research will field test a combined algal and cattail water treatment system for the removal of Se and other contaminants from river water. This novel system, which was developed from a mesocosm study at UC Berkeley, is designed to generate a clean water supply for the SCH or other habitat related projects. Its efficiency for pollutant removal will be tested using a 16-cell pilot treatment system to be constructed by the Imperial Irrigation District on a site adjacent to the Alamo River.

The main goal of this project is to create, develop and monitor a constructed wetland water treatment system (CWTS) to provide clean water for the Species Conservation Habitat at the Salton Sea (SCH). We are requesting funding in the amount of \$1,065,993 to cover UC Berkeley research over the 3-year period, January 1, 2013 to December 31, 2015. UC Berkeley is collaborating with the Imperial Irrigation District (IID), which will provide funding in the amount of \$355,350 to cover the initial construction of the CWTS as well as partial funding of the operation and maintenance of the facility over the 3-year period.













The CWTS wetland design was developed from CADWR-funded studies carried out by UC Berkeley (April 1, 2010 to the present). The proposed Salton Sea CWTS will be built in January 2013 by our collaborator, IID, at a 10-acre site near the Alamo River. The experiments will be initiated in February 2013 and monitoring will begin May 2013 (see *Attachment 5*). In the second and third years, this work will be continued in the field to investigate the long-term performance of the CWTS.

To carry out Tasks 2 through 7 (see Schedule, *Attachment 5*), a team of 2 postdoctoral scholars (a wetland ecologist and a microbiologist/chemist) and 1 laboratory assistant (to help with laboratory work ~15h/week) will be required. The salaries and benefits of the researchers (which constitute the main expense over the 3-year period) increase every year at the rate indicated in the budget below (*Attachment 6B*). Additional expenses will be incurred for the operation and maintenance of the CWTS facility, travel expenses, chemical analyses (Se, N, P and S, etc), x-ray absorption spectroscopy at SSRL (for Se speciation), as well as miscellaneous materials and supplies essential to the research monitoring program.

Postdoctoral scholars will visit the CWTS at the Salton Sea to conduct field surveys every month. Once we have gathered the field samples, the researchers will make 3 trips every year to Stanford Synchrotron Radiation Light Source (SSRL) at Stanford University to conduct Se speciation analyses. Expenses that include monthly field trips to the Salton Sea, trips to the SSRL at the Stanford University and delivery of soil and river water from the Salton Sea to the laboratory at UC Berkeley are calculated in the 'other direct costs' section of the budget with a total of \$460,980 over three years. UC Berkeley is asking for \$90,000 dollars (\$30,000 each year) from the FAP grant to cover their share in the Operation and Maintenance (O & M) costs of the CWTS. IID will cover \$52,200 per year of the O & M expenses. UC Berkeley charges 25% of the direct costs as overhead (25% is the overhead rate for state agencies grants and is referred to as "indirect costs"). For Tasks 2-7 it is difficult to breakdown the costs by task. This

is because the tasks overlap and use many of the same materials. Also, in research one is often confronted with deviations in the proposed plan that may be more or less expensive than planned. To accomplish Tasks 8 and 9 UC Berkeley is requesting 5% of the total direct costs for project administration (for such activities as purchasing, preparation of monthly cost reports to CADWR, as well as quarterly research progress reports to CADWR and IID). The itemized costs to perform the proposed research by UC Berkeley are summarized in the attached Budget sections below (*Attachment 6*).

## Attachment 5. Schedule

WORK PLAN- SCHEDULE	1st year (divided by month)												2nd year	3rd year
Tasks	1	2	3	4	5	6	7	8	9	10	11	12		
1. Construction of the CWTS														
2. Plants and algal cells setup														
3. Wetland cells establishment														
4. Algal population density experiment														
5. Residence time experiment														
6. Algal species experiment														
7. Wetland maturity experiment														
7.1 Measuring efficiency for Se removal														
7.2 Determining Se accumulation														
7.3 Analyses of Se speciation and ecotoxicity evaluation														
8. Administration:														
Preparation of invoices and monthly budget narratives														
9. Reporting:														
Submission of quarterly, annual and final reports.														

## Attachment 6. Budget

A) UCB - IID combined first year budget. IID will cover costs to construct the CWTS. UC Berkeley is requesting CADWR funding under the FAP grant to develop this research project over three years for a total of \$1,065,993.

Budget category	Non-State Share (Funding Match)	Requested Grant Funding	Total	% Funding Match	Comments
(a) Direct Project Administration Costs		\$13,338	\$13,338		UC Berkeley will take care of administration of the research project on the CWTS. We will submit quarterly and yearly reports to CADWR and IID. We will also prepare monthly report of expenses and invoicing to CADWR.
(b) Land Purchase/ Easement	\$5,000		\$5,000	100%	Lease cost based on \$50.00/acre for approximately 20 acres for five years
(c) Planning, Design, Engineering and Environmental Documentation	\$15,000		\$15,000	100%	IID has completed CEQA documentation for the water transfer Habitat Conservation Design effort provided by HCP Implementation Team.
(d) Construction/ Implementation	\$115,000		\$115,000	100%	IID will fund the construction of the CWTS
(e) Environmental Compliance, Mitigation and Enhancement	\$15,000		\$15,000	100%	IID will coordinate with Imperial County prior to implementation of this project. The IID Habitat Conservation Program (HCP) Implementation Team will monitor the project for environmental compliance.
(f) Construction Administration	\$17,250		\$17,250		Assumed to be 15% of construction cost because of additional environmental constraints and logistic issues with play construction. IID will conduct Construction Administration.
(g) CWTS Research and Monitoring Program		\$306,783	\$306,783		UC Berkeley. See detailed UC Berkeley budget below.
(h) Construction/ implementation Contingency	\$11,500		\$11,500	100%	IID calculated assuming 10%
(i) Operation and maintenance costs	\$52,200	\$30,000	\$82,200	63.5%	Shared by IID with funds that UC Berkeley is requesting from the CADWR FAP grant
(j) Grand Total (Sum rows (a) through (i) for each column	\$230,950	\$350,121	\$581,071		Total estimated amount first year

*B) UCB Budget for a three years research program.* This proposal grant is asking for a total of \$1,065,993 for this research program that will be conducted over three years.

	<b>Year #1</b>	<b>Year #2</b>	<b>Year #3</b>	<b>TOTAL</b>
Salaries:				
Postdoc Researcher #1 @1.00 FTE	45,670	47,040	48,452	141,162
Postdoc Researcher #2 @1.00 FTE	40,442	41,655	42,905	125,002
Lab Assistant @12.00/hr @.40FTE	10,022	10,323	10,633	30,978
<b>Salaries Total</b>	<b>96,135</b>	<b>99,019</b>	<b>101,989</b>	<b>297,142</b>
Benefits:	Rate: 19.70%	Rate: 20.30%	Rate: 20.90%	
Postdoc Researcher #1	8,997	9,549	10,126	28,672
Postdoc Researcher #2	7,967	8,456	8,967	25,390
2 Lab Assistants	-	-	-	-
<b>Benefits Total</b>	<b>16,964</b>	<b>18,005</b>	<b>19,093</b>	<b>54,062</b>
Travel	48,660	48,660	48,660	145,980
Materials and Supplies	75,000	75,000	75,000	225,000
Participant Support Costs	-	-	-	-
Wetland Operation & Maintenance Cost	30,000	30,000	30,000	90,000
Other Direct Costs Total	153,660	153,660	153,660	460,980
<b>Total Direct Costs</b>	<b>266,759</b>	<b>270,684</b>	<b>274,743</b>	<b>812,184</b>
<b>Administrative Support 5% of TDC</b>	<b>13,338</b>	<b>13,534</b>	<b>13,737</b>	<b>40,609</b>
<b>Modified Total Direct Cost</b>	<b>280,097</b>	<b>284,218</b>	<b>288,480</b>	<b>852,793</b>
<b>INDIRECT COSTS 25%</b>	<b>70,024</b>	<b>71,054</b>	<b>72,120</b>	<b>213,198</b>
<b>GRAND TOTAL:</b>	<b>350,121</b>	<b>355,272</b>	<b>360,600</b>	<b>1,065,993</b>

## **Attachment 7. Field Research Plan**

### **1. Construction and design of the pilot CWTS.**

*Location.* The pilot CWTS will be located in an approximately 10-15 acre exposed playa near the mouth of Alamo River discharging into the Salton Sea to the south (33°11'56.73"N, 115°35'57.18"W). Its borders are the Alamo River to the north, Red Hill Bay Road to the south, Garst Road to the east and Red Hill to the west (see *Attachment 8, Figure 1*). The site is an exposed playa whose slope is less than 0.1%. The average elevation on the property is approximately 71 m below mean sea level.

*Site characteristics.* The site is an exposed playa and currently not in use for any specific purpose. The site has no existing utilities. The major utilities in adjacent roads consist of agricultural drains and electricity that can be used to power the pumps and other facilities after wetland construction. According to data of the Calipatria CIMIS station (1990-2009), temperatures in the southern Salton Sea area typically average 13°C in the winter and 32 °C in the summer. Rainfall in this area is usually very low, at 7 cm/year, while average evapotranspiration rate is high, at 1.8 m/year. Rain occurs predominantly from November through March. Because evapotranspiration rates are substantially higher than rainfall, residence time of the water in the wetland should be kept to a minimum to maximize water flows to the SCH especially during summer.

*Construction and layout.* The pilot CWTS will be constructed by the Imperial Irrigation District (IID), which will be responsible for obtaining the necessary permits, site survey and preparation, final design, wetland construction, facility installment, including electricity, pumps, weirs, and pipes. After construction, IID will share the responsibility with UC Berkeley to operate and maintain the CWTS for the next three years. The layout of the CWTS, which will consist of a sedimentation pond (30-m x 50-m), eight long-length treatment cells (each 6-m x 120-m) and eight short-length cells (6-m x 60-m), is illustrated in *Attachment 8, Figure 2*. The cells will be constructed according to the general design criteria (*Attachment 8, Table 1*). All cell inlets will consist of 5-cm PVC irrigation pipe with a PVC butterfly control valve and 5-cm impeller flow meter installed inside the inlet pipe to regulate and monitor inlet flow. Outlets will consist of 25-cm galvanized metal pipe with measured v-notch weir.

*Initial CWTS set-up.* After construction of the CWTS, each cell will be filled with river water to a level of 0.5 meter. The bottom of each cell will be disturbed to re-suspend the fine particles and the cell refilled with water to the top of the bank. The cells will be left alone for at least a day to allow gravitational settling that will sort particles by grain size (see *Attachment 8, Figure 3*). This act will be repeated at least two more times to create a clay liner at the surface of the bottom to prevent seepage. Once the clay liner is properly formed (i.e., when the water level remains constant indicating that there is no more

seepage), the water level will be adjusted to a level of 10 cm to keep the clay liner wet and intact. The cattail treatment cells will be filled with a 20 cm layer of cattail shoots harvested from drains nearby. In constructed wetlands, the fallen cattail litter layer of the upper sediment substrate is required to provide habitat and nutrients for the microbes which carry out the microbial transformations essential for pollutant removal. Because it normally takes some time for a wetland to mature and form a substantial litter layer, we intend to overcome this problem by using locally available cattail shoots.

*Planting plan.* The cattail treatment cells will be flooded and transplants of cattails collected from nearby wetlands will be planted by hand at a plant spacing of 1 m square. Cattail (*Typha latifolia*) was selected as the target wetland plant for several reasons. It has a high rate of biomass production, which is important for providing fallen litter and other organic material essential for microbial Se volatilization and pollutant immobilization. It is also highly competitive under field conditions, and tends to dominate over other wetland plant species in the Salton Sea area. After planting, river water will be pumped (at a low speed of 1,000-3,000 gallons/day) through each of the cattail-planted cells for the next four months. For the algal species experiment, the eight short-length algal treatment cells will be planted with different algal species including *Chlorella* sp, *Scenedesmus* sp and two local algal species. The results obtained from this experiment will be used to determine the algal species and algal population density to be used in the four main algal-cattail treatments.

## **2. Initial experimental plan.**

*Experiment 1: Determination of minimum residence time.* After successful establishment of the cattail-planted cells (i.e., at about four months from transplantation), we will use the four long-length algal-cattail treatment cells to determine the minimum residence time needed to reduce Se and fertilizer nutrients to the required low levels. Residence times of 3, 6, 9 and 12 days will be tested by manipulating water depth (5-60 cm for cattail cell and 20-90 cm for algal cells) and hydraulic loading rate. Selenium removal efficiency and nutrient removal efficiency will be monitored as described below.

*Experiment 2. Quantitative evaluation of the algal treatment cell component.* To test the concept that the inclusion of an algal treatment cell will result in high rates of Se volatilization and therefore less accumulation of Se in the CWTS ecosystem, the selected algal species will be added to the four long-length algal treatment cells at four different population densities (including zero algae added for one of the cells). In addition to determining the efficiencies of Se and nutrient removal, the algal density of each algal cell will be monitored monthly and maintained at constant levels (as far as possible) throughout the experimental period. Quantitative measures of Se volatilization occurring in each of the cattail treatment cells will be estimated every three months by mass balance.

*Experiment 3. Algal species comparison.* After the clay liner is in place, we will grow different algal species in the eight short-length algal treatment cells for one month. Initially, we will compare four different species of algae (*Chlorella* sp, *Scenedesmus* sp and two local algal species) in terms of their efficiency in removing Se from river water through Se volatilization and through Se accumulation in their biomass, as well as the removal of fertilizer nutrients. Each species will be grown at different population densities to determine the effect of population density on Se removal. The raceway pond will be installed with a paddle wheel to ensure adequate circulation (the water depth and the paddling speed will be adjusted to create the most appropriate mixing and aeration conditions for algal growth and pollutant removal). Algal growth will be monitored by measuring chlorophyll concentration. Removal efficiencies of Se and nutrients will be monitored by collecting water samples for total Se, N, P and S, at the inlets and outlets of each algal cell each month. To verify the mass balance estimates of Se volatilization in the algal cells, volatilization rates will be measured under laboratory conditions at UC Berkeley.

*Experiment 4. Changes with wetland maturity.* As the cattail wetland matures over the three-year period, two different types of change are likely to take place – changes in pollutant removal efficiency and changes in the accumulation of pollutants within the wetland ecosystem. Firstly, pollutant removal efficiency should increase as the fallen cattail litter and other organic matter in the sediments accumulate. This in turn will lead to a substantial increase in microbial habitat and activity, which should result in increased rates of Se removal (through volatilization and immobilization). Secondly, even though the introduction of the algal treatment cell should lead to considerable losses of Se to the atmosphere through volatilization, there will nevertheless be some buildup of Se in the sediments. Depending on the chemical species of Se building up in the sediments, there is a potential risk of Se ecotoxicity.

In Experiment 4 we will determine the changes over time in the removal efficiency of the pollutants, Se, N, P and S between the inlets and outlets of the CWTS on a monthly basis over the three-year experimental period. In order to assess the changes taking place in the wetland sediments over time we will measure soil organic matter (SOM) and the changes in the thickness of the microbial biofilm (consortium) on the surfaces of the fallen litter layer. This will be carried out monthly by 2-cm dia profiling of the sediments to a depth of 25 cm. These results will enable us to establish the correlative dependence of pollutant removal efficiency on SOM and microbial populations within the sediments. Such information is an important building block in further attempts to increase the pollutant removal efficiency of constructed wetland water treatment systems.

The sediment core profiles will also be used to determine the amounts and chemical forms of Se building up in the sediments over time. The potential bioavailability and ecotoxicity of residual Se forms accumulating within the CWTS ecosystem will be assessed

by speciating Se in sediments, plants and other biota using high-energy synchrotron-based x-ray absorption spectroscopy (XAS). This research will be conducted using the sediment cores and biota tissue samples over time for the measurement of total Se and determination of the different chemical forms of Se. The XAS measurements will be conducted at the Stanford Synchrotron using beam-time access already approved by SSRL. The XAS research will be supervised by Dr. Soo In Yang who has considerable experience and expertise in carrying out this type of research.

### **3. Field Sampling and Protocols**

*Sampling and analysis - team responsibilities and logistics:* The UC Berkeley CWTS research team will consist of two post-doctoral researchers who will make monthly sampling visits from UC Berkeley to the Salton Sea to monitor changes in the algal and cattail treatment cells. A sample coding system will be used to ensure that the field samples could be identified and tracked accurately through all the processing stages (see *Attachment 8, Table 2*). The on-site visits will take 3 days after which time the researchers will return to the UC Berkeley laboratory with the collected samples to complete chemical and other analyses, e.g., determination of Se volatilization rates of collected water samples from the algal cells. Standardized laboratory techniques will be followed to ensure both the reproducibility and accuracy of the chemical analyses. Speciation of residual Se in sediment, plant and other biota will be conducted at the Stanford Synchrotron.

*Influent and effluent water sampling:* On a monthly basis, influent and effluent water sampling for total Se, N, P and S will be carried out for each of the wetland cells. The sampling will consist of 250 ml grab samples according to the Bottle Submersion Method (Brynes, 1994). The acid-rinsed 250-ml polyethylene sample bottle will be lowered by hand or extension rod into the water. The sample will be preserved immediately after sampling by acidifying with Trace Metal Grade concentrated nitric acid (HNO<sub>3</sub>) to pH < 2. After acidification, the sample will be transported at ~ 4°C for immediate laboratory analyses. The concentrations of the elements will be determined on an unfiltered sample after vigorous digestion.

*Pore water sampling:* The sampling for pore water Se in each cattail cell will be conducted on a 2 m x 20 m grid system. Each unacidified Se sample will be filtered by passing through a 0.1-µm membrane filter using a 10 cm-long Rhizon Soil Moisture Filter, which is inserted into the sediment and attached to a 20-ml vacuum tube and allowed to fill. This sample will provide a sterile unacidified sample of pore water from the composite 0-10 cm sediment profile. The sample will be preserved immediately after sampling by acidifying with Trace Metal Grade HNO<sub>3</sub> to pH < 2. Once acidified, the samples will be transported at ~ 4°C for laboratory analysis.

*Wetland cattail:* The biomasses of cattail shoots and roots will be collected every three

months from three randomly selected 1m x 1m quadrats. Whole cattail plants will be removed from the wetland area with the use of a spade and representative shoot samples (i.e., actively-growing green leaf tissue) removed. Complete shoots will also be collected for seasonal biomass measurements. The below-ground portion (i.e., root sample) of the whole cattail will be extracted from the soil and rinsed on-site to remove sediments. Grab samples of standing and fallen cattail litter, seed and seed heads will be collected during the fall and winter months, which will also include dead leaf litter (standing and fallen). During the growing season, cattail samples will consist of green shoot (leaf and stem) and root tissues. Collected cattail samples will be packed and preserved ~ 4°C for immediate transport to the laboratory. Wetland cattail biomass estimates per sampling area (1m x 1m) will be determined with randomly selected whole shoots of cattails (Kufel, 1991). Per unit area frequency of cattails will be calculated from replicated counts. The individual cattail biomass measurements will provide an estimate of the total above-ground seasonal biomass per unit area.

*Algae sampling:* During the monthly visits, samples from the algal cells will be collected using the Bottle Submersion Method. The appropriate number and quantity of samples will be determined by the algal biomass produced under field conditions. At least replicate 1 L samples will be collected from each algal treatment cell. The collected algal samples (i.e. water containing the algae) will be frozen and transported for laboratory analysis. Algal growth and population density will be assessed monthly by measuring biomass dry weight and comparing it with extracted chlorophyll contents. In the laboratory the algal biomass samples will be processed with acetone and DMSO to extract and measure total chlorophyll by spectrophotometric methods. Other analytical methods will also be performed on water and algal biomass samples.

*Biological specimens:* Biological samples, i.e., biofilms, macroinvertebrates, fish and amphibians, from the CWTS will be collected every three months and preserved on ice and transported to our laboratory for total Se analysis and Se speciation by XAS. Macroinvertebrates will be surveyed seasonally using Hester-Dendy multilevel benthic colonization plates (Hester and Dendy, 1962) and emergence trap collection (Downing and Rigler, 1984). Multiple collection sites will be located in different habitats near the inflow, middle, and outflow of the Alamo River wetlands. The Hester-Dendy colonization plates will be deployed on the substrate and placed in plastic bags upon retrieval. Invertebrates collected with the emergence traps will be trapped in a plastic jar containing 100 ml of 50% ethyl alcohol. Collected invertebrates will be identified in the laboratory. Specimens were identified to family or genus level using Merritt and Cummins (1996). Fish and amphibians will be sampled in the spring and fall using nine minnow traps in the wetland as described in Cochran (1998). The minnow traps will be set up for 28 days and checked three times each week on the same days to standardize the study. Each captured fish and amphibian will be placed in the bucket and identified on

the site or in the laboratory.

*Sediment sampling:* Sediment sampling will be based on a 2 m x 20 m grid system in each cattail treatment cell. This sampling will be performed with a Cole-Palmer sediment core sampler (10 inch long x 1 inch diameter) with a replaceable butyrate liner. This will provide an *in situ* measurement of sampled sediment with near-zero profile contamination. The wetland area to be sampled will be first cleared of plant matter. The thin-walled probe will be inserted into the sediment to just beyond the desired depth (15 cm). The probe will then be removed from the sediment, and the liner will be removed from the probe according to Boulding (1994). The liner containing the sediment profile sample will be capped and stored on ice for transport to the laboratory.

*Physicochemical parameters:* At each monitoring visit, the physicochemical surface water parameters that may affect the availability and uptake of Se and other nutrients by cattail and algae in the CWTS will be measured *in situ* in the inflow and outflow of each treatment cell. We will measure surface water pH, electrical conductivity, temperature, dissolved oxygen, and salinity. Three replicates will be measured for each parameter using a Hanna Instruments HI 9828/4 Multiparameter Water Quality Portable Meter (Woonsocket, RI, USA) to properly assess the effect of mechanical alternations in the environmental conditions.

*Selenium mass balance:* Sources and sinks of Se in the algal cell and cattail cell, and a Se mass balance, are summarized in *Attachment 8, Figures 4 A and B*. The total Se input and output from each cell will be estimated from total Se measurements in the inflow and outflow. The mass of Se stored in the water and sediment components (i.e., mineral soil and litter) will be estimated as the product of their respective volumes and concentrations. Selenium biomass accumulation will be estimated using the mean Se concentrations measured in cattail shoot and root tissues and algal biomass. The rates of Se volatilization will be calculated as the difference between the net input of Se and the mass left in the system.

*Water budget:* The water budget will be calculated as the difference between total water input and output. The input will include inflow (pumped river water), rainfall [and ground water] while the total water output includes outflow, seepage and evapotranspiration (see *Attachment 8, Figure 5*). The following general equation is used to determine a water budget for each CWTS cell:

$$I + P + G - O - ET - S = 0$$

where,

I = inflow (pumped river water)

P = precipitation  
 G = ground water recharge  
 O = outflow  
 ET = evapotranspiration  
 S = seepage

Inflow and outflow measurements in each cell will be made based on two important variables: 1) water level of the treatment cell, and 2) the crest elevation of the weir installed at the outlet of each cell. These data are then used with the Kindsvater-Shen equation that relates water head to rate of outflow as follow:

$$Q = 0.121 C \tan\left(\frac{\theta}{2}\right) (h + k)^{5/2}$$

where,

Q = Discharge (m<sup>3</sup>/s)  
 C = Discharge coefficient  
 θ = Notch angle  
 h = Head (m)  
 k = Head correction factor (0.001 m)

Local precipitation and evapotranspiration data will be obtained from the Calipatria CIMIS station of the California Irrigation Management Information System (CIMIS). In addition, seepage will be estimated by the budget equation mentioned above.

#### **4. Analytical Methods and Procedures to be used in the Laboratory**

*Quality assurance and control:* Analytical methods and protocols will be conducted using standard quality procedures, i.e., certification of operator competence, recovery of known additions, analysis of externally supplied standards, duplicates and reagent blanks, and calibration with standards.

*Water analysis methods:* Dissolved Se and S will be measured directly from water samples with inductively coupled plasma-dynamic reaction cell-mass spectrometry (ICP-DRC-MS) and atomic absorption spectrometry (AAS) according to EPA and Standard Methods (EPA 3010A, 1992) after acid-digestion. For total N and P will be analyzed using QuikChem IV automated system and Lachat methods according to EPA instruction (1983).

*Sediment analysis methods:* Sediments will be removed from capped butyrate liners, cut

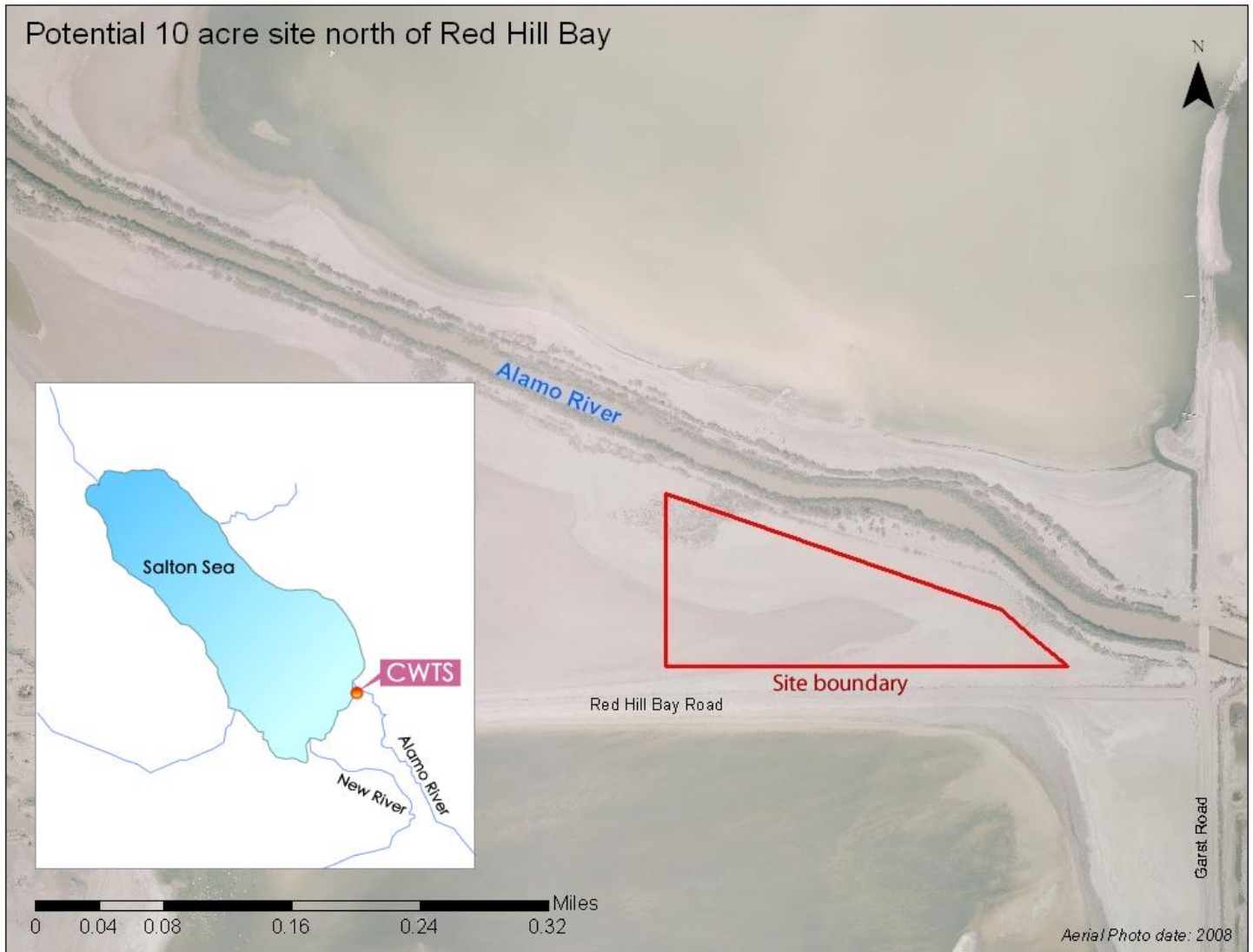
into 5 cm profile sections (0-5, 5-10 and 10-15 cm), air-dried, ground, and acid-digested with HNO<sub>3</sub>/HCL followed by measurement for all trace elements of interest with ICP-DRC-MS.

*Total Se analysis method in biological samples:* Wetland biological tissue samples will be dried at 70°C, weighed, ground in a Wiley Mill to pass a 40-mesh screen, and samples will be acid-digested with HNO<sub>3</sub>/HCl (Zarcinas et al., 1987). Total Se will be measured with ICP-DRC-MS.

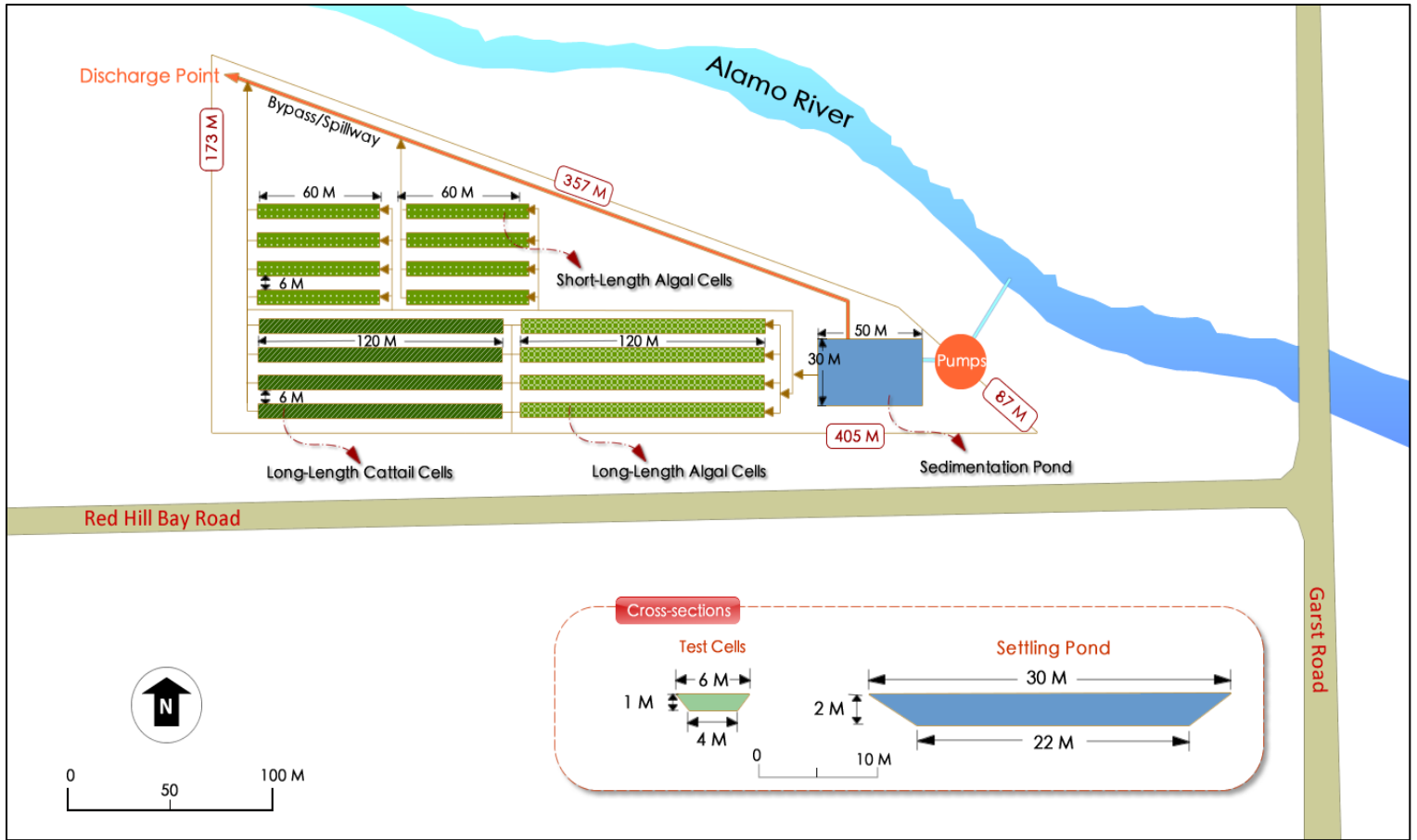
*Evaluation of Se ecotoxicity (Se speciation):* Collected sediment, plant, algae, biofilm, benthic invertebrates, insects, fish, and bird excreta samples will be transported into the lab under the refrigerated conditions. All the samples will be ground using pestle and mortar in liquid nitrogen and then packed into 2mm X-ray absorption spectroscopy (XAS) sample holders followed by preservation at -80 °C. The prepared samples will be transported on dry-ice to the beamline 7-3 of the Stanford Synchrotron Radiation Lightsource. Se speciation study will be conducted using X-ray absorption near-edge structure and extended X-ray absorption fine structure at Se K-edge range. All the samples will be measured inside of helium-filled cryostat maintaining the temperature at approximately 10 Kelvin (-263.15 °C) to minimize atomic thermal vibrational effect in defining Debye-Waller factor and radiational damage to the samples. The collected raw data will be processed using a suite of XAS program, EXAFSPAK (George and Pickering, 2001). A typical XAS beamline setup is shown in *Attachment 8, Figure 6*.

*Statistical analysis:* All data will be analyzed using PASW Statistics 18 to conduct factorial ANOVA and Multiple regression analyses. Factorial ANOVA tests will be used to determine the influence of plant species, organic material, wet-dry cycling and retention time (sampling period) and their interactions on Se removal, Se volatilization and Se distribution. All tests will be conducted at a 95% confidence interval ( $\alpha = 0.05$ ). Significant differences will be reported at  $p \leq 0.05$ , and sample variance will be expressed as the standard error.

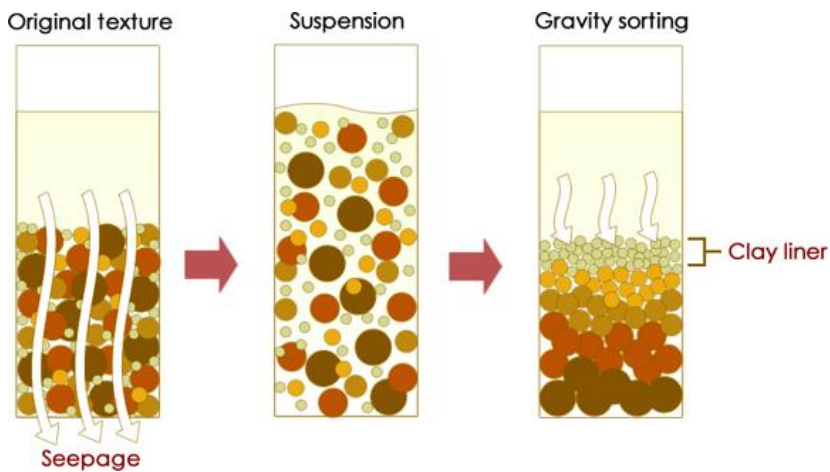
## Attachment 8. Site Maps, Photos and Design Figures



**Figure 1. Proposed site for the constructed wetland treatment system (CWTS).** The location of the proposed CWTS is along the southern shore of the Salton Sea in Imperial County, California (33°11'56.73"N, 115°35'57.18"W). IID has proposed a ~10-acre site near the mouth of the Alamo River for the construction of the pilot wetland. The area is located between the Alamo River and Red Hill Bay Road (outlined in a red)

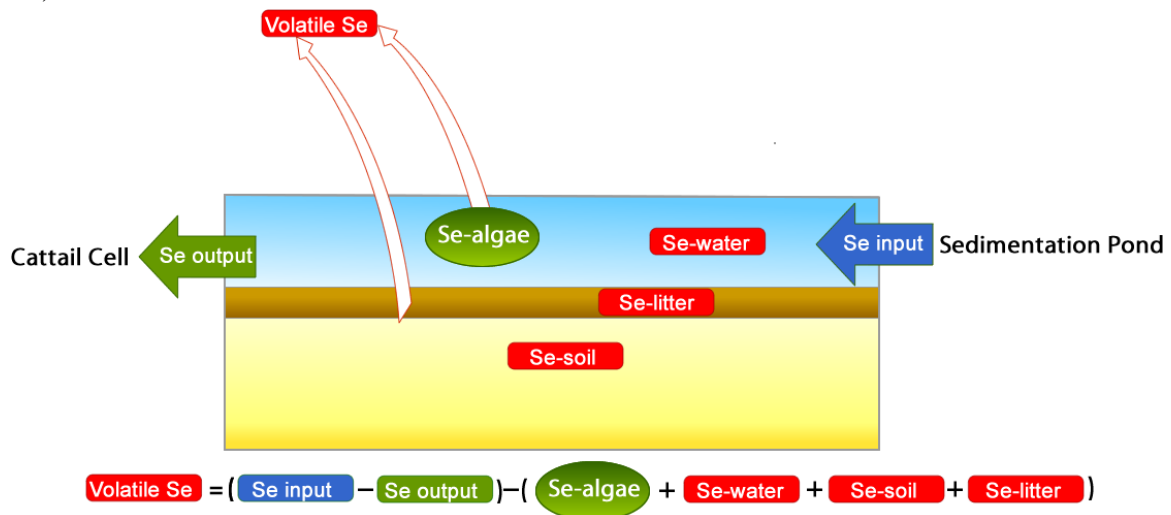


**Figure 2. CWTS design:** Includes sedimentation pond, eight short-length cells and eight long-length cells. Different algal species will be tested in eight short-length cells. One selected algal species will be grown in four eastern long-length cells while cattail will be planted in four western long-length cells.

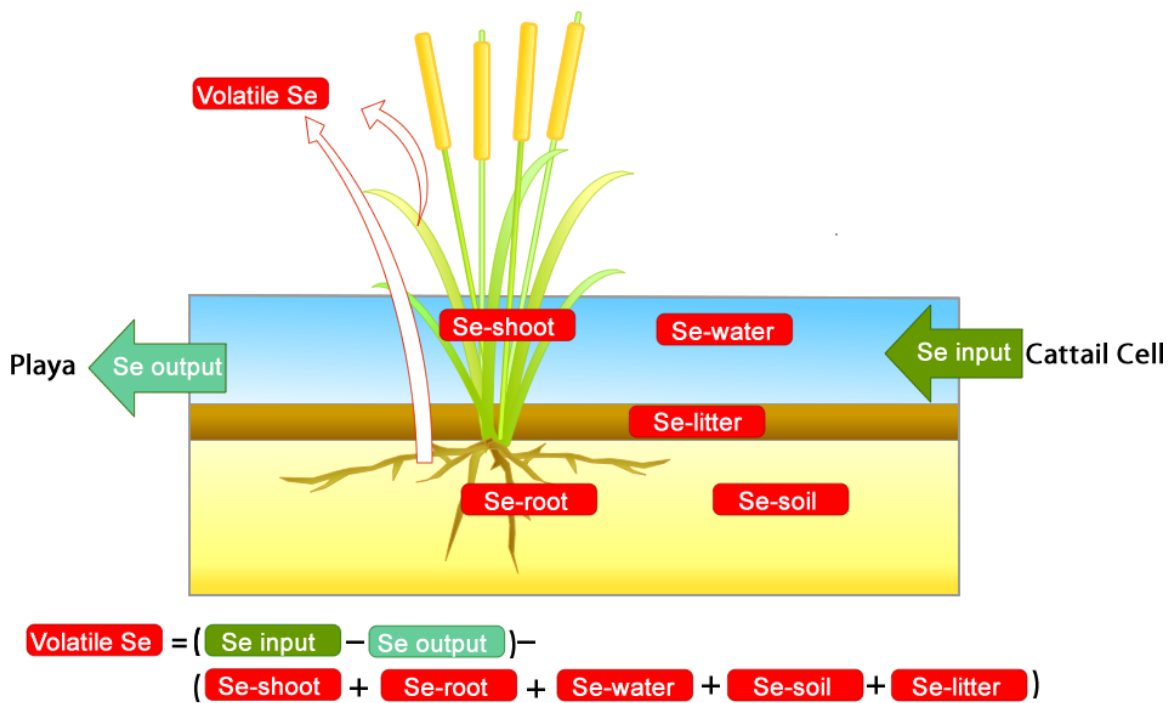


**Figure 3. Seepage prevention in CWTS cells.** A clay liner will form at the bottom of the cell, through repeated gravity sorting, to prevent seepage.

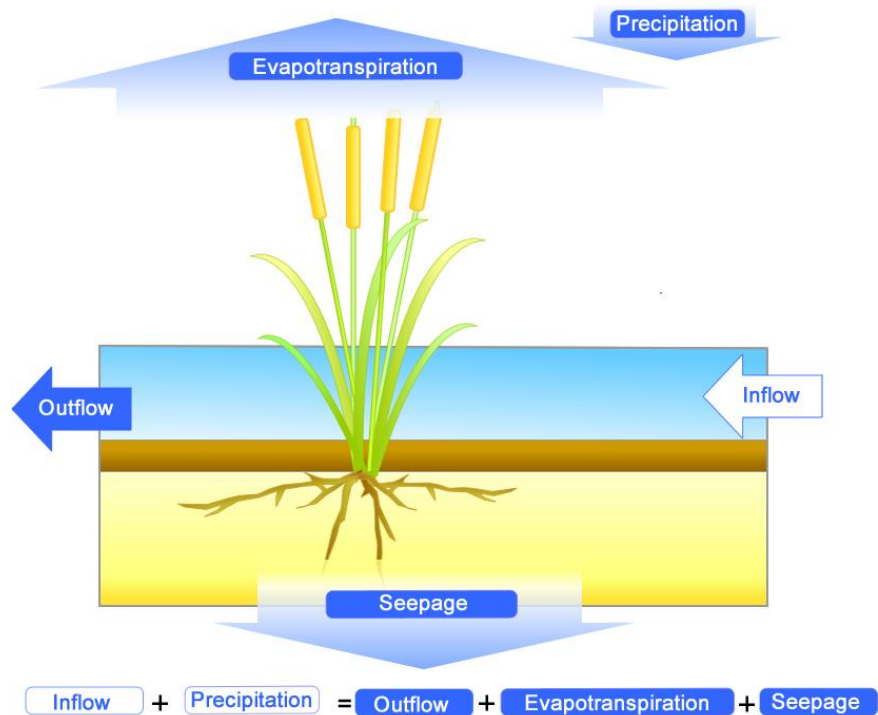
A)



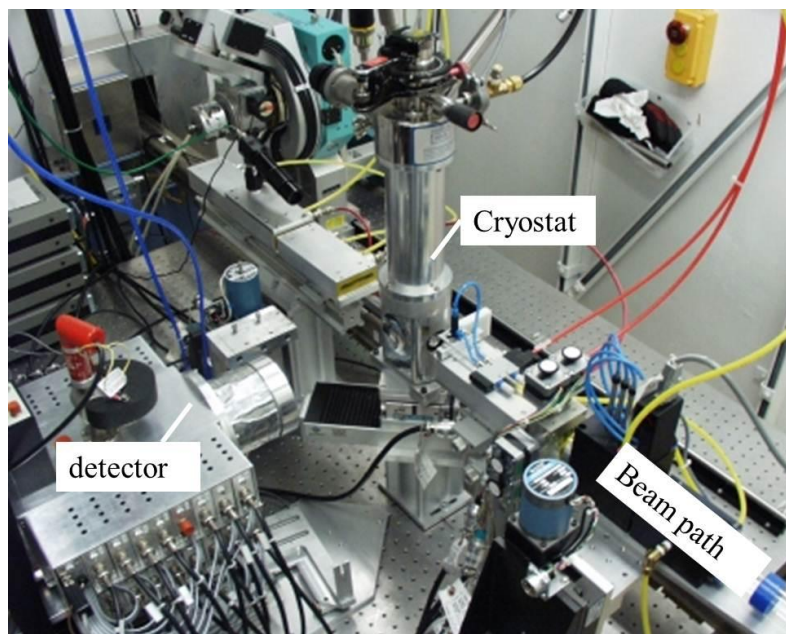
B)



**Figure 4. Se mass balance diagrams.** (A) Mass balance for Se in the algal cells; (B) Mass balance for Se in cattail cells



**Figure 5. Water budget.** The water budget is the difference between total water input and output. The input will include inflow (pumped river water), rainfall (and ground water) while the total water output includes outflow, seepage and evapotranspiration.



**Figure 6. Synchrotron XAS technology to study Se speciation.** The picture illustrates a typical XAS beamline setup used to identify Se species in environmental samples.

**Table 1. Design specifications for the CWTS.**

Parameter	Sedimentation Pond	Short length cells	Long length cells
Bank slope	1:2	1:1	1:1
Bottom slope	0-1:200	0-1:200	0-1:200
Depth (m)	2	1	1
Bottom width (m)	22	4	4
Top width (m)	30	6	6
Length (m)	50	60	120
Cell numbers	1	8	8
Cell area (m <sup>2</sup> )	1,500	360	720
Total Area (m <sup>2</sup> )	1,500	2,880	5,760
Total pumping rates (gallons/day)*	428,000		

\* based on the residence time of 2 days.

**Table 2. Sampling and Analysis. CWTS sample coding system\***

Code	Description	Type	Period
C.SW.1	Cell 1-8	Surface Water	Monthly
C.PW.1	Cell 1-8	Pore Water	Monthly
C.S.1	Cell 1-8	Sediment	Monthly
C.C.1	Cell 1-8	Cattail	Monthly
C.A.SW.1	Cell 1-8	Surface Water In Algal Pond	Monthly
C.A.PW.1	Cell 1-8	Pore Water In Algal Pond	Monthly
C.A.S.1	Cell 1-8	Sediment In Algal Pond	Monthly
C.A.B.1	Cell 1-8	Algal Biomass In Algal Pond	Monthly
C.B.I	CWTS	Benthic Invertebrates	Monthly
C.B	CWTS	Biofilms	Monthly
C.I	CWTS	Insects	Monthly
C.B.E	CWTS	Bird Excreta	Monthly
C.F	CWTS	Fish	Monthly

\*Sample coding system that allows identification and tracking of the field samples through out the processing stages. Each code is produced with the first characters of the sample types.

## Attachment 9. Letters of support

### IID LETTER OF SUPPORT



[www.iid.com](http://www.iid.com)

August 19, 2012

Norman Terry, Ph. D.  
University of California at Berkeley  
Plant and Microbial Biology  
111 Koshland Hall  
Berkeley, CA 94720-3102

Dear Doctor Terry:

The Imperial Irrigation District (IID) is pleased to provide this letter in support of the University of California at Berkeley's proposed constructed wetland treatment system for the Salton Sea.

The continuation of this promising technology to treat agricultural return flow water is a very important step in the development of the habitat based components of the Salton Sea restoration. Development of a field test pilot program, located at the Salton Sea is the next step in the long range development of this technology for removal of selenium by volatilization.

IID will continue to provide logistic, final design, and construction support for the constructed wetland treatment system. IID believes that the continuation of this project will help address the need for the development of a more sustainable water source for habitat creation and Salton Sea restoration.

Sincerely,

Bruce Wilcox  
HCP Environmental Program Manager  
Imperial Irrigation District

UNIVERSITY OF CALIFORNIA, BERKELEY

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September 6, 2012

Salton Sea Financial Assistance Program  
Department of Water Resources  
1416 9<sup>th</sup> Street, Room 1148  
Sacramento, CA 95814

TO WHOM IT MAY CONCERN:

I am writing to lend my strongest support to the research proposal entitled "Field Test of a Novel Wetland Treatment System to Provide Clean Water for the Salton Sea Species Conservation Habitat," which is being submitted to the Salton Sea FAP by Professor Norman Terry. Although I have known Professor Terry for more than 30 years as a University of California colleague, we do not collaborate in research and I am not involved with the research proposal under consideration. My commentary on his proposal in this letter stems solely from my longtime interest in research and teaching as related to water and soil quality, from my own recent research emphasis on water quality in near-coastal wetland systems.

Professor Terry has spent a number of years developing constructed wetlands as "design-with-Nature" water treatment systems to remove nutrients and harmful contaminants from wastewaters. This approach takes advantage of the unique soil and water chemistry in wetlands along with the physiology and biochemistry of the aquatic plants and algae in them to purify wastewaters that otherwise would become eutrophic or be hazardous to wildlife and humans. Of special concern with respect to ecotoxicity is the element selenium. Professor Terry has become internationally recognized for the development of methodologies for using aquatic plants and algae to remove this toxic element from wastewaters by transforming it into a gas that poses no environmental threat because it is diluted into the atmosphere and carried away. He has perfected this approach in a series of mesocosm studies and is poised to apply it to impaired water resources that in principle could be used to supply the Salton Sea. His project, which involves optimization of his approach for Salton Sea conditions, is surely destined to succeed in its goals.

Even my brief remarks here should make it evident why I am enthusiastic about the proposed project, both for its scientific content as a full-scale demonstration of proof-of-concept and for its high potential to benefit the Salton Sea Species Conservation Habitat. I give my whole-hearted endorsement to it absolutely without reservation as an excellent, low-risk investment of public funds.

Sincerely yours,

Garrison Sposito  
Betty & Isaac Barshad  
Chair in Soil Science

UNIVERSITY OF CALIFORNIA, BERKELEY

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SANTA BARBARA • SANTA CRUZ

J. KEITH GILLESS, DEAN  
OFFICE OF THE DEAN  
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TELEPHONE: (510) 642-7171  
FAX: (510) 642-4612  
EMAIL: gilless@berkeley.edu

September 7, 2012

Salton Sea Financial Assistance Program  
Department of Water Resources  
1416 9<sup>th</sup> Street, Room 1148  
Sacramento, CA 95814

To Whom it may concern:

I write in support of the research proposal submitted to the Salton Sea Financial Assistance Program (FAP) by Professor Norman Terry of the College of Natural Resources, Department of Plant and Microbial Biology, entitled "Field Test of a Novel Wetland Treatment System to Provide Clean Water for the Salton Sea Species Conservation Habitat".

As Dean of the College of Natural Resources, I recognize the importance of this area of research in its promise to transform impaired water systems. This technology holds the promise that it could be used to recycle the billions of gallons of California agricultural irrigation drainage water which, at present, is wasted and cannot be utilized due to the high selenium content. The College of Natural Resources is fully committed to helping implement this program should it be funded by Salton Sea FAP.

Sincerely,

A handwritten signature in black ink, appearing to read 'J. Keith Gilless'.

J. Keith Gilless  
Dean

## **Attachment 10. Operation and Maintenance Plan**

Operation and maintenance efforts made by UC Berkeley and IID for the CWTS will take place over a three-year period following construction. IID will monitor the operation of the CWTS weekly while UC Berkeley will make bi-weekly visits for the first growing season (March – August 2013), and then a minimum of once a month for the next three years, with additional inspections as required. These efforts are described in the table below.

<b>Operations Parameter</b>	<b>Maintenance Requirement</b>
Maintenance access	Accessibility to each treatment cells and other facilities will be maintained in good condition.
Pumping	Pumping rates will be controlled based on research needs.
Clogging control	Trash and litter will be removed from the screen, pipes, weirs and other facilities to prevent clogging.
Basin excavation	Periodical removal of bottom sediment is necessary to maintain the settling capacity of the basin.
Influent and effluent monitoring	Inflow and outflow will be monitored to investigate potential seepage in the system.
Soil conditions	Soil amendments may be required to minimize seepage
Residence time	Inflow and water depth will be manipulated to create various residence times. Valves at the inlet will be used to control the inflow. Flashboards in the weir at the outlet will be adjusted to maintain water levels.
Plant maintenance	Cattail is a competitive species in the local area. Massive growth is expected and preferred. Plant maintenance for cattails will be minimized while harvest will not be necessary.
Re-planting / Re-inoculation	Replanting will still be required if they are damaged or fail to grow, especially for some algal species.
Disposal of plant waste	Cattail litter produced in the CWTS will be recycled as a fallen litter layer. Therefore, there is no need to dispose of plant waste.
Fencing	Fencing may need to be installed to keep people and animals out.
Nuisance control	Wetlands might attract rodents. Burrowing animals, e.g. muskrat, will be checked frequently. When found, we will remove them, replace embankment materials, and reseed.
Storm water runoff / River water	Top of cell banks will be raised 15 cm higher than the ground to prevent runoff from entering the cell. Spillways will be installed to discharge extra river water from the site.
Mechanical support systems	Maintenance of pumps, pipes, valves, weirs and other electricity facilities will be conducted periodically.

## ***Attachment 11. References***

- Boulding, J. R. Description and sampling of contaminated soils, 2nd Ed. Lewis Pub., Boca Raton, (1994) 326 pp.
- Byrnes, M. E. Field sampling methods for remedial investigations. Lewis Pub., Boca Raton, (1994) 254 pp.
- California Irrigation Management Information System (CIMIS)-available on web-  
<http://www.cimis.water.ca.gov/cimis/welcome.jsp>, Aug, 2012.
- Cochran, M. W. Abundance and diversity of aquatic species in the experimental wetlands at the Olentangy River Wetland Research Park after four growing seasons. In Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1997. Mitsch, W. J., Bouchard, V. eds., The Ohio State University, Columbus, OH, 1998; pp183-187.
- Craft, C. B. Biology of wetland soils. In: Richardson, J. L., Vepraskas, M. J. eds., Wetland Soils: Genesis, Hydrology, Landscapes and Classification. Lewis Publishers, Boca Raton: FL. 2001.
- Downing, J. A.; Rigler, F. H. A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters, Blackwell Scientific, Oxford. 1984.
- EPA Methods of Chemical Analysis of Water and Waste, EPA-600/4-79-020 Revised March, 1983.
- EPA Method 3010A. In Methods for Chemical Analysis of Water and Wastes; U.S. Environmental Protection Agency: Washington, DC, 1992.
- Gao, S.; Tanji, K. K.; Lin, Z. Q.; Terry, N.; Peters, D. W. Selenium removal and mass balance in a constructed flow-through wetland system. J. Environ. Quality 2003, 32(4), 1557–1570.
- George, G.N. and I.J. Pickering. A Suite of computer programs for analysis of X-ray absorption spectra – available on web-<http://www-ssrl.slac.stanford.edu/exafspak.html>, August, 2012.
- Hester, F. E.; Dendy, J. S. A multiple sampler for aquatic macroinvertebrates. Transactions of the American Fisheries Society 1962, 91:420-421.
- Kufel, I. Lead and molybdenum in reed and cattail-open versus closed type of metal cycling. Aquatic Botany 1991, 40, 277-288.
- Lin, Z.; Terry, N. Selenium removal by constructed wetlands: quantitative importance of biological volatilization in the treatment of selenium-laden agricultural drainage water. Environ. Sci. Technol. 2003, 37(3), 606–615.
- Merritt, R.W.; Cummins, K.W. An introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing, Dubuque, Iowa, 1996; 862p.

Nair, V. D.; Graetz, D. A.; Reddy, K. R.; Olila, O. G., Soil development in phosphate-mined created wetlands of Florida, USA. *Wetlands* 2001, 21(2), 232-239.

Zarcinas, B.A., B. Cartwright and L.R. Spouncer. Nitric acid digestion and multi-element analysis of plant material by Inductively Coupled Plasma Spectrometry. *Commun. in Soil Sci. Plant Anal.* 18 (1987) 131-146.

Zhang, Y. Q.; Zahir, A. Z.; Frankenberger, Jr. W. T. Factors affecting reduction of selenate to elemental selenium in agricultural drainage water by *Enterobacter taylorae*. *J. Agric. Food Chem.* 2003, 51(24), 7073–7078.